COMMERCIALIZATION ANALYSIS OF SBIR FUNDED TECHNOLOGIES

THESIS

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Abstract

The United States Small Business Innovation Research (SBIR) Program invests $2.2 billion annually into domestic innovation stimulation. The Department of Defense (DoD) contributes almost $1 billion of that investment; of which the Air Force accounts for 25%. Commercialization, either the transfer to programs of record or further industrial investment, is the program's objective. Data from this research indicates that Air Force programs have a 7.6% commercialization rate; representing an opportunity to improve. Leveraging best practices from industry; this research provides a method to align investments with needed capabilities. This method exploits established user need taxonomies, the DoD Joint Capability Area (JCA) listing and the National Aeronautics and Space Administration's SBIR taxonomy, to categorize SBIR efforts. This categorization allows for needs based innovation portfolio management. Metrics are developed that identify several technologies of interest that over perform and underperform relative to the overall portfolio. This development of metrics and visualization tools provides managers a new means to control and improve their innovation investments. This needs based mapping facilitates sharing and coordination amongst aerospace SBIR stakeholders. This thesis concludes by recommending improvements to the existing JCAs, the SBIR topic development process and the establishment of an aerospace SBIR community of interest.

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To Father, Mother, and Wife

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Theodore A. Rask

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COMMERCIALIZATION ANALYSIS OF SBIR FUNDED TECHNOLOGIES

I. Introduction

The Air Force Chief of Staff, General David L. Goldfein, stated during the 2018 Air Force Association Air, Space, and Cyber Conference that we are in a "world that has returned to an era of great power competition" (Goldfein, 2018). This point was echoed within the 2018 National Defense Strategy (NDS) as "the re-emergence of long-term, strategic competition between nations" (United States Department of Defense, 2018). The United States military is required to refocus its mission beyond ill-equipped factions and nations. The 2018 National Security Strategy laid out by the Commander-in-Chief identifies this reemerging threat as "the revisionist powers of China and Russia" (The President of the United States, 2018).

Combatting the reemerging powers of peer nations requires a military composed of both manpower and equipment capable of tipping the scale in its favor. The NDS elaborates on the needs for emerging technologies and innovation:

> New commercial technology will change society and, ultimately, the character of war. The fact that many technological developments will come from the commercial sector means that state competitors and non-state actors will also have access to them, a fact that risks eroding the conventional overmatch to which our Nation has grown accustomed. Maintaining the Department [of Defense]'s technological advantage will require changes to industry culture, investment sources, and protection across the National Security Innovation Base (United States Department of Defense, 2018).

The Small Business Innovation Research (SBIR) program represents a significant investment in domestic innovation. The SBIR program spans multiple government agencies as shown in Figure 1, with annual investments of over $2.2 billion flowing directly into the national industrial base (Fiscal Year 2015 SBIR and Small Business Technology Transfer (STTR) Annual Report, 2015). The Department of Defense SBIR program alone obligated over $956 million in SBIR funding in 2015 (U.S. Small Business Administration, 2018).

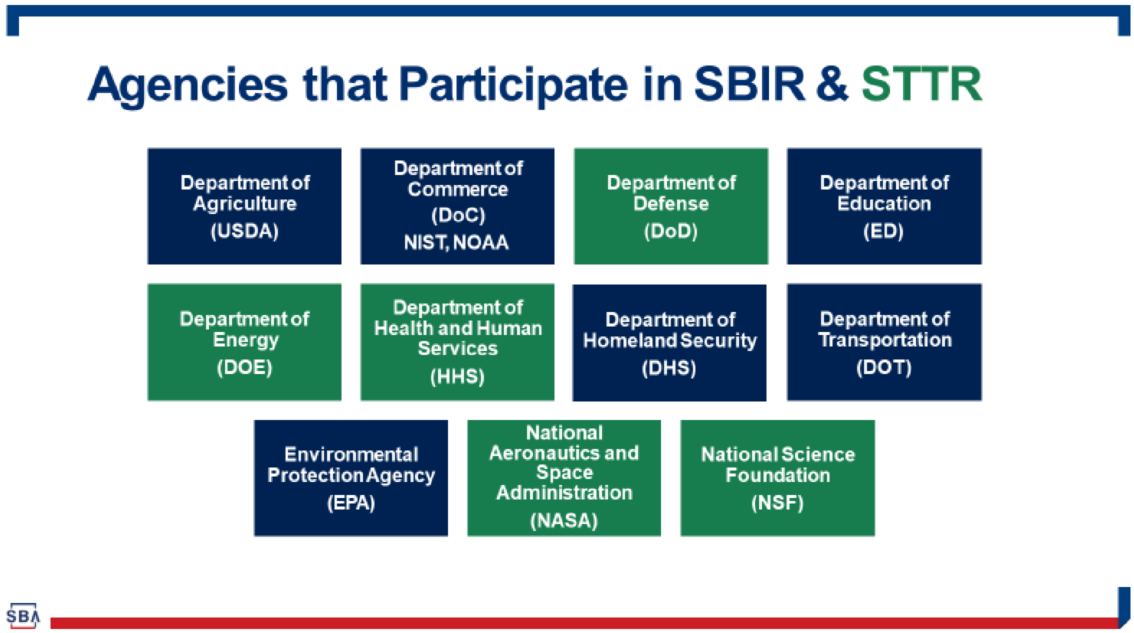

Figure 1. SBIR Participating Agencies (U.S. Small Business Administration, 2018)

While these investments are made, how effective are they? The current measure of success and objective for the SBIR program is commercialization. A transition from phase II to III represents a commercialized program. Commercialization occurs when a program transitions to a new funding source, which can be either commercial or separate government funding stream (United States Department of Defense, Office of Small Business Programs, 2018). The government expectation is that the research and development of the first two phases of SBIR funding contracts will result in a commercially viable product. This transition stimulates the industrial base with the potential for the infusion of innovations to meet defense needs.

1.1 Problem Statement

Commercialized DoD SBIR programs provide both an economic and a technological benefit. While the current benefit serves as a starting point, this research seeks to enhance the performance of our investments and increase our benefit. Prior to starting this research, low transition rates were expected; the price for success is typically a path of failures. In analyzing data from the last three years, this research found a USAF SBIR transition rate of 8%.

SBIR's objective is industrial base stimulation. Commercialization is only one lens for considering program performance; it does not capture benefits realized through learning and technological diffusion from uncommercialized programs. In spite of its limits as a measure, commercialization serves as a well-grounded starting point for measuring performance.

At present, it is not clear how to judge the 8% success rate. Venture capital backed firms, a commercial source of innovation, have a 25% survival rate (Gage, 2012). This rate considers a separate unit of analysis; while similar, firm and innovation performance are not the same. Further, there are market differences; the DoD pursues riskier technology as the lead or lone user. What is drawn from this is that high failure rates are to be expected. Next, looking towards the commercial sector identifies pathways to potentially improve performance. Lack of alignment with market need is a leading cause of venture capital backed firm failure (CB Insights, 2018). Assuming the underlying mechanism of alignment is generalizable to defense innovation, how aligned are Air Force SBIR investments with Air Force needs?

This research seeks to understand patterns in performance in USAF SBIR data in general. Further, it takes a step towards measuring SBIR alignment with our needs. This research assumes that the Air Force SBIR program can achieve performance beyond 8%. The objectives of this research are to develop tools and metrics to support decision makers and improve SBIR program performance.

1.2 Research Objectives

- Examine patterns within the SBIR data set to determine:
    - Commercialization performance behaviors

    - Insight into existing policy performance
- Expand upon the existing SBIR commercialization data set for broader analysis that accounts for:
    - The viability of current DoD acquisition taxonomies
    - Commercialization Reports
    - Original Customer Needs
    - Errors within the existing data set
- Establish a capability-based taxonomy for SBIR topics to include:
    - A Systems Engineering Approach
        - Mission Need
        - Function
        - Form
        - Context
    - Existing DoD capability-based Joint Capability Area taxonomy

1.3 Research Focus

The focus of this research is the commercialization performance of Air Force Phase II programs, specifically the application of existing and new taxonomies to those programs for commercialization analysis.

1.4 Research Questions

- What is the commercialization performance of Air Force SBIR Programs?
- What are the unique behaviors or patterns demonstrated within that commercialization performance?
- What methods can be developed to investigate and explain those behaviors and patterns?

- What specific SBIR technologies of interest identified by those methods?

1.5 Methodology

A phased approach was applied for this effort, more details are provided in chapter 3, however, a summary is below:

- Phase I: Generation and Correction of a Data Set
    - Generate a data set of Air Force SBIR program commercialization data from Fiscal Year 2015 to July 2018
    - Correct the data set for errors and missing data that are inadequate for a commercialization analysis
    - Conduct an initial analysis to determine the commercialization rate of SBIR programs
- Phase 2: Exploratory Data Analysis
    - Use existing categorical data within the dataset to examine trends concerning commercialization
    - Develop additional categorical methods (taxonomies) to apply to each SBIR program for commercialization analysis
    - Determine the viability of existing and new categorical methods
    - Conduct a commercialization analysis of the SBIR data set using a viable categorical method
- Phase 3: Trend Analysis and Tool Development
    - Identify interesting and new commercialization trends for future research
    - Develop tools to support SBIR management and decision maker insights

1.6 Assumptions

It is assumed that no changes have occurred to the SBIR program from when the data set was obtained (July 2018) to the completion of this thesis document. Further, changes beyond the program are not significant enough to impact the results herein. This assumption is bolstered by discussions with the research sponsor; the program has had stable management for the time frame considered.

It is assumed that the statistical sampling of the SBIR database for coding provides insight for the entire population. The DoD Joint Capability Area (JCA) taxonomy process was applied to a random sample of 225 SBIR contracts for this thesis effort. The logical assignment process for assigning JCAs was interpreted similarly across the research team during the panel of rater's assignment process.

It is assumed that the commercialization data derived from Company Commercialization Reports (CCRs) is accurate. The self-reporting nature of the CCRs from participating SBIR firms has been of concern by the GAO (U.S. Government Accountability Office, 2013; U.S. Government Accountability Office, 2014). Validation of this commercialization data by further investigation of a focused portfolio of SBIR programs is suggested for future research.

1.7 Limitations

- The SBIR program data set consists of only Air Force SBIR programs from Air Force Fiscal Year 2015 to July 2018. This timeline captures a period of constant leadership. Further, it is a timeframe that is favorable for follow-on interview-based research; human memory can degrade over time and a decade is a rule of thumb for case study research.

- SBIR programs within the data set that fail to include adequate cost or date data to determine Phase II contract closeout are excluded from analysis. If a contract is unable to be deemed closed, it is still receiving SBIR program funding and has potential to be commercialized up until the closure of that contract.

- Open SBIR Phase II contracts are excluded from analysis, these open contracts are still receiving SBIR program funding and have potential to be commercialized up until the closure of that contract.

- Monetary commercialization dollars are the only examined success factor, the intrinsic value of diffused technology from SBIR efforts in the DoD or AF is not analyzed.

- Categorical analysis of commercialization performance is only performed on 178 SBIR contracts that are assigned a Joint Capability Area (JCA) category and fall within established JCA categories that meet population requirements of three or more SBIR contracts.

1.8 Implications

This research provides deliverable products to the Air Force Small Business program office as well as a wealth of data and analysis to support future research. First, it provides a comprehensive data set for this effort and follow-on efforts. Second, it provides results of an exploratory analysis; providing a useful step towards understanding dead ends and identifying future research paths. Third, it provides a method for encoding and analyzing SBIR programs with an established DoD needs taxonomy, known as the Joint Capability Area (JCA) listing, generated by the Joint Staff. Finally, visualizations of this needs-based data coding provides a tool to observe needs-based investments as well as needs-based portfolio performance.

This research provides tools that are immediately useful and data to fuel future research. Needs-based metrics provide a possible explanation of commercialization performance behavior and a direct link between SBIR efforts and user needed capabilities. Categories within the taxonomy that indicate either high or low commercialization performance provide avenues for follow-on research. The data set generated within this research provides a functional building block to which additional program data or other component SBIR data can be added.

1.9 Preview

This research effort provides an exploratory analysis of commercialization performance within Air Force SBIR funded technologies. The DoD SBIR program is an established means to help answer the nation's call for improvements to the National Security Innovation Base, with almost $1 billion of obligated funding in 2015 alone. The Air Force SBIR program has an 8% commercialization rate at present; improvements over this rate can yield increased benefits with existing investments. Leveraging insight from the commercial sector, this research applies established defense capability taxonomies to characterize innovation investments and performance as a function of needs.

With the above end state in mind, this document will take a typical scholarly format/path. Chapter II presents a literature review to frame and support this research. The underlying concepts of innovation that define the SBIR program will be introduced. A brief history and overview of the SBIR program will be provided with specific attention to the Air Force SBIR program and its sister services. Finally, an overview of existing relevant DoD taxonomies and categorical methods will be explained along with their applicability to the SBIR program.

Chapter III describes the methods used to answer the concerns of this research. A data set of Air Force SBIR program commercialization data will be generated. A commercialization analysis will be conducted using data already contained within that data set to explain positive and negative commercialization performance behavior. New categorical methods will be developed to assist with commercialization analysis of that data. The most viable categorical method will be applied to the data set, and the data will be reanalyzed for commercialization performance behavior. New and interesting commercialization trends will be identified as areas of interest for future research.

The results of an analysis of the data set using the prescribed methods is explained in Chapter IV. The SBIR dataset is the product of several various government sources, and the generation and any refinements to the dataset is described. A breakdown of the categorization selection process, to include failures and successes, is listed. The development of a viable categorization method that aligns with user need is explained. A partial coding of the contract population is performed using the viable method, and commercialization performance of that sample is reported. Unique behaviors and patterns encountered during analysis are identified. The implications and accuracy of the results are discussed.

Finally, findings of the analysis conducted during the research and their impact on solving the identified commercialization and categorization issues are characterized in Chapter V. Closure of established research questions for commercialization performance and behaviors is provided. Paths for future and follow-on SBIR commercialization research are identified. The actual impact of the research on the Air Force SBIR program and the Department of Defense is explained.

II. Literature Review

2.1 Chapter Overview

This chapter provides insight into the Small Business Innovation Research (SBIR) Program, with particular attention being given to the Air Force SBIR Program. A summary overview of the general flow of this literature review can be found in Figure 2. First, this literature review will define the innovation environment. Then, it will refocus towards the United States SBIR program, breaking the program down from the National level to the Department of Defense (DoD) and DoD Agency level. Next, the review considers commercialization efforts across the DoD Agencies, to gain insight into differences and similarities. Finally, the baseline data has limited categorization to support analysis. This chapter concludes with descriptions of applicable categorization methods.

Figure 2. Literature Review Overview

2.2 The Innovation Environment

Innovation can be defined as "the practical implementation of an idea into a new device or process" (Schilling, 2013); it can be seen in the development of the jet aircraft or something as simple as the mechanical pencil. These ideas are the product of creative innovators as shown in Figure 3. Innovators create the idea and translate it into an innovation.

Several theories have been developed to conceptualize the forms an innovation process takes and what behaviors are exhibited in those forms (Abernathy & Utterback, 1975; Christensen, 2016; Rogers, 2003; Schilling, 2013; Utterback, 1996; Von Hippel, 1994; Zmud, 1984). The technology and information related to an innovation effort are subject to several mechanisms. These mechanisms help explain the subsequent effects on the transfer, protection, and development of innovation efforts.

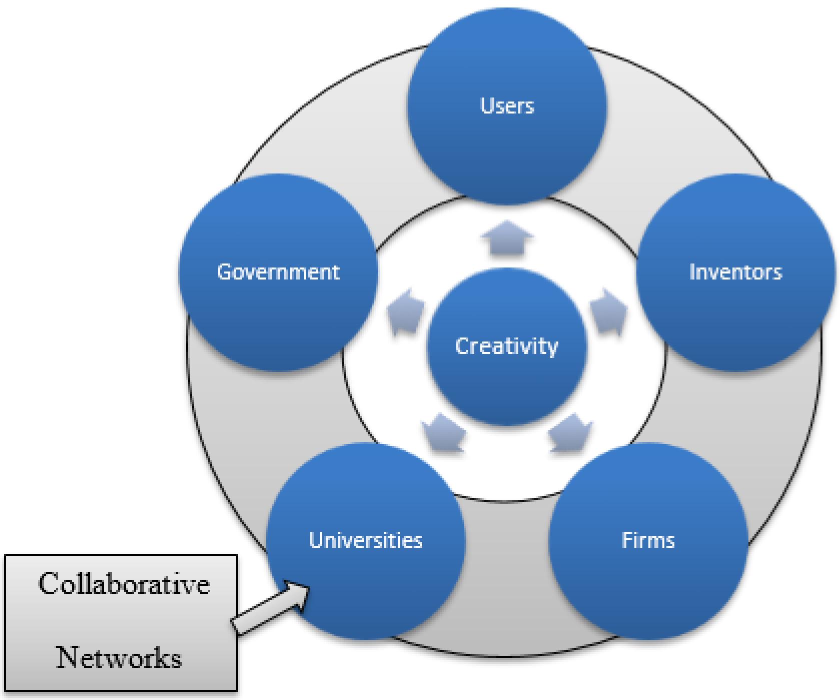

Figure 3. Sources of Innovation (Schilling, 2013)

2.2.1 Creativity

Creativity is the fuel that drives innovation and can be defined as the ability to generate ideas that are both novel and useful. Two major categories categorize creativity: the individual level and the organizational level. Individual creativity requires that a person be able to utilize associative thinking, which is the ability to make connections and ideas from seemingly unrelated items to find solutions or identify a future need. These individuals have sufficient judgment to screen those ideas for only the ones most likely to succeed and can convince others of the promise of those ideas. Those who have a moderate amount of knowledge in various fields of study are the best associative thinkers; their associative barriers are low, and they have just enough knowledge to understand each field of study (Dyer, Gregersen, & Christensen, 2011).

Organizations build upon individual creativity by producing a creative output that is the function of the individuals within the organization and the factors that influence the way they act and behave (Schilling, 2013). The structure, organization, routines, and incentives within an organization can either promote or limit the creativity of its employees. Organizations struggle to determine the mix that will promote creativity while also meeting the bottom line. Many organizations have sought to promote a fun workspace and flexible work hours to maximize a creative environment (Ford, Newstrom, & McLaughlin, 2004). Once an idea is created, significant efforts by inventors, users, and firms must be made for it to become an innovation.

2.2.2 Individual Inventor

The argument that leaders are born and not made can be applied to the individual inventor. Are the best inventors genetically predisposed to do so, did they learn this ability, or is it a mix of both? The most successful inventors or innovators balance discovery and delivery skills (Dyer, Gregerson, & Christensen, 2011). Discovery skills consist of making connections on seemingly unrelated items, showing a passion for inquiry, being intense observers, spending significant time and energy finding and testing ideas through a diverse network of individuals, and continuously experimenting by trying out new experiences and piloting new ideas. Delivery skills are the entrepreneurial traits that allow the patenting or commercialization of those ideas. Inventors have the courage to challenge the status quo and take smart risks; they have either the delivery skills to make innovations happen or hire individuals that possess those skills to act on their behalf.

2.2.3 User Innovator

The most knowledgeable individuals to seek out how to improve technology are the users of the technology themselves (Schilling, 2013). User innovators do not initially seek profits from their innovations; they seek performance improvements for their use. They seek improvements to current products, submit new ideas and suggestions for innovations to existing manufacturers, or develop a new innovative product on their own. User innovations can consist of incremental improvements or an entirely new design that can completely change an industry or generate a new one altogether.

2.2.4 Firm Research and Development

Firms typically consider their most significant source of innovation to be their internal research and development efforts (Schilling, 2013). Firms partake in both basic research and applied research; basic research seeks to increase understanding of a topic or field without an immediate commercial application, while applied research increases understanding to satisfy a specific need. Development applies knowledge gained through research to produce a useful device, process, or material.

The requirement for these research and development efforts can originate from new scientific discovery (scientific-push) or in response to an explicit or perceived market need (demand-pull) (Zmud, 1984). Research and development conducted internally is at the explicit cost to the firm and requires significant resources. However, the internal effort also has two benefits. First, it yields intellectual property and in turn exclusivity. Second, it results in learning; the firm can exploit learning curves and be in a better position to comprehend and exploit new knowledge relevant to the innovation (improved absorptive capacity).

2.2.5 University and Government Research

Universities have historically been a significant source of innovation since university faculty are commonly encouraged or required to conduct research that could lead to useful innovations (Schilling, 2013). The commercialization rights for these innovations are typically at the sole discretion of the university, who usually shares the profits with the creator. A significant non-commercial contribution to innovation efforts is the publication of the research itself, with additional research or innovation efforts to be conducted by other organizations or individuals.

Government research and development efforts to improve public welfare, national defense, and economic conditions (boosting Gross Domestic Product) are an ongoing global effort. These efforts are secured through research conducted at government laboratories, public research and development funding, and science parks and innovation incubators. Government laboratories in the United States conducted over $57 billion in research and development activities in 2015 (National Science Foundation, 2018). Public research and development funding includes programs such as the Small Business Innovation and Research (SBIR) program and the Small Business Technology Transfer (STTR) program from the U.S. Small Business Administration discussed later in this chapter.

There are efforts to collocate innovators and firms to hasten innovation. Science parks are regional districts that are typically placed near universities to foster research and development collaboration between the government, universities, and private industry. Innovation incubators are firms with the sole purpose of providing business resources and advice for newly emerging businesses to include networking services to help develop a business network.

2.2.6 Collaborative Networks

Firms often collaborate with users, suppliers, complementary product suppliers, competitors, government entities, universities, and non-profit organizations (Schilling, 2013).

Users and suppliers have the most direct interaction with both the product and the firm and are typically the collaborator of choice. Adner and Kapoor argue that the innovations that are the product of a firm, its suppliers, and its complementors create an innovation ecosystem consisting of upstream and downstream challenges (Adner & Kapoor, 2010). Collaborating with complementary firms on innovations provides a complement a competitive edge over other complements while also enabling a higher performance capability than the summary effort of the product and its complement. The summation of the SBIR and STTR collaborative network encompasses Henry Etzkowitz's (2006) triple-helix model of academia, industry, and government; the model states that in areas of cutting edge research, or new knowledge, economic goals are met through government-supported academic input.

2.2.7 The Innovation Model

The prevalent model of innovation is derived from the works of Abernathy and Utterback (Abernathy, 1978; Abernathy & Utterback, 1978; Abernathy & Utterback, 1975; Utterback, 1996). Akiike (2013) argues that the model has gone through several iterations since its initial creation by Abernathy and Utterback in 1978. The general theory developed by Abernathy and Utterback, as shown in Figure 4, is that in the early stages of development, product innovations are developed at a staggering rate to meet a need for maximum product performance. Over time, the focus is placed on innovating the manufacturing process itself, shifting the rate of innovation from product to process innovations to minimize product costs.

Utterback (1996) further refined the model into the fluid, transitional, and specific phases of an innovation effort. In the fluid phase, the highest rate of significant innovation takes place; organic organizations focus on radical product innovations in a fragmented, unstable, and unestablished market. In the transitional phase, markets for the product innovation become established and start to grow. A dominant design becomes established and process innovations to manufacture that design begin to match the level of effort innovating the product itself. In the specific phase, the focus shifts entirely towards incremental product and process innovations to develop a specific dominant design with a high level of efficiency for maximum profit.

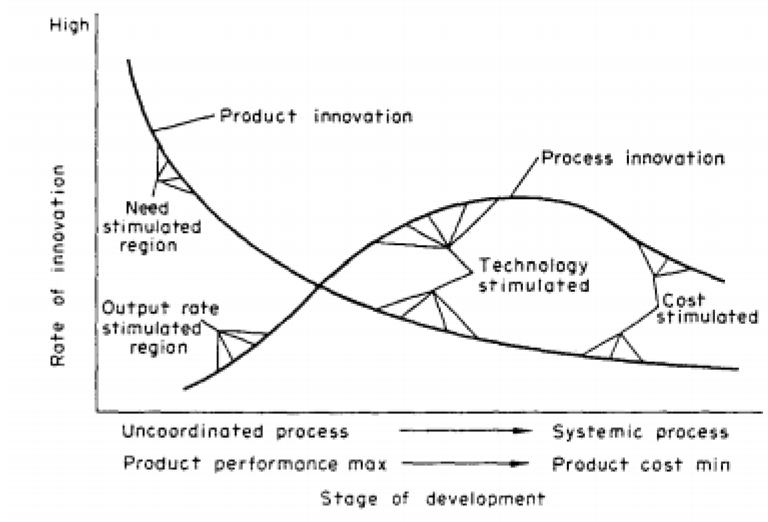

Figure 4. Innovation and Stage of Development

Reprinted from Omega, Vol. 3, James M Utterback and William J Abernathy, A dynamic model of the process and product innovation, Page 645, Copyright (1975), with permission from Elsevier.

Utterback (1996) points out that established technology within the specific phase can be invaded, overwhelmed, and reversed to a previous phase by a significant radical innovation. Applying Utterback's point, if an immature, fluid SBIR innovation is applied to a technologically mature product within the specific phase, the product's phase and technological maturity could be reversed. DoD organizations that oversee sustainment and modernization efforts of technologically mature weapon systems may be hesitant to absorb an innovation that could impact that maturity.

If a SBIR effort is an advanced state of the art, complex system, Hobday (1998) argues that Utterback's approach to the innovation process is inadequate. He specifies that these products and systems are never mass produced, product life cycles can extend decades, decisions to invest may take months or years, and innovation lags far behind the delivery of the product as new features are added and systems are upgraded and modified (Hobday, 1998). In light of this conundrum, a different point of view and model may be required.

Bower and Christensen theorized two separate forms of innovation: disruptive and incremental technologies (Bower & Christensen, 1995; Christensen, 2016). Disruptive innovations impact a market or industry and can bring a wave of technological change. Incremental innovations can be viewed as small innovations that keep the product line relevant. The Air Force SBIR program continually searches for new capabilities for future needs (disruptive innovations) and improvements to current capabilities for current needs (incremental innovations). The Air Force could need a directed energy product on an F-15 in one SBIR contract and a new coating for corrosion protection on that same F-15 in another.

Christensen (2016) describes the five laws of disruptive technology. These laws provide insight into the challenges faced by a disruptive innovation. He points out that "developing a technology typically goes against what customers and investors want now" and that a disruptive technology "should be framed as a market challenge, not a technological one." This theory translates directly to the main issue of this research effort, commercializing disruptive technologies in markets that may not necessarily exist. Benefits of the SBIR program can be found within the five laws as well, concerning the small businesses participating in the program. Christensen (2016) explains that "small markets don't solve the growth needs of large companies"; the typical market for a SBIR effort cannot provide the 20% annual net sales growth needed for a 6-billion-dollar company of $1.2 billion. Christensen (2016) further argues that a small organization dedicated to a disruptive technology will be able to dedicate full attention to and be willing to undertake the inherent failures of a new market and technology.

2.2.8 Innovation Transfer and Protection Mechanisms

Innovation diffusion is the adoption of innovative ideas and technologies across various entities such as firms, markets, or nations. The diffusion of innovations theory, developed by Rogers (2003), places the adopters of innovation across a normally distributed curve of adopter population to market share. The theory states that only 2.5% of the total population and a minimal market share are the innovators. The rest of the population and subsequent market share consists of early adopters (13.5%), early majority (34%), late majority (34%), and laggards (16%). Tzokas and Saren (1992) found that supply-side factors have an ever-increasing role in the organizational diffusion of innovations. They identified that the more an innovation is standardized, or the more an expectation by adopters that it will become the standard, the more rapid the diffusion by adopters. A SBIR effort that represents a groundbreaking disruptive technology will encounter more difficulty being diffused into the DoD rather than an "incremental" improvement to an existing standard technology or system.

Firms with a higher absorptive capacity, or the ability to recognize that value and then assimilate and apply new information within a firm, are better oriented to benefit from diffusion. Mazzucato and Robinson (2018) have cited the National Aeronautics and Space Administration's (NASA's) shift to public sector innovation efforts, such as the NASA SBIR program, as a negating factor affecting NASA's absorptive capacity. The DoD acquisition process has transferred much of the internal technical engineering and integration efforts outside of the DoD (Miles, 2009). Doing so may have affected the DoD's absorptive capacity to diffuse innovations through research and development efforts such as the SBIR program.

Technological spillovers occur when the "benefits from the research activities of one firm (or nation or other entity) spill over to other firms (or nations or other entities)" (Schilling, 2013). These contributions have a positive impact on overall national or global innovation output. The intrinsic benefits provided by a spillover of SBIR technologies to the DoD may not be represented by commercialization dollars alone. The strength and likelihood of spillovers are affected by the strength of a firm's protection mechanisms and the stickiness of the information itself. Information stickiness is the cost incurred to transfer information from one firm to another; the stickier the information, the less likely a spillover will occur (Szulanski, 1996).

An innovation effort such as a SBIR program typically develops both advanced technological and tacit information related to that innovation; a heavy focus is placed on protecting that information for monetary and security reasons. While patents and non-disclosure agreements provide legal protection, information stickiness takes advantage of the information itself. Information stickiness is a function of the monetary and knowledge cost associated with tacit and explicit information. Stickiness consists of the costs to obtain and understand the tacit information of an innovation and the cost of codifying the sheer volume of related explicit information. Von Hippel (1994) argued that the stickiness of information provides both benefits and issues to an innovation effort. Stickiness can help protect valuable information from being intentionally diffused to competitors, thereby providing a unique benefit of information protection for U.S. SBIR technologies from peer nation industries. Benefits decrease when information becomes stickier and more costly to internally diffuse, thus negating any utility to the overarching organization who created it.

The stickier a set of information becomes, the more design responsibilities and profits lie with the source of that information such as users or manufacturers. Sticky user information places more functional design responsibilities on the user, and stickier technological information shifts those efforts towards manufacturers. The SBIR program develops user needs (e.g., SBIR topic solicitations) that can be based on rather sticky information that pulls the functional design effort away from the SBIR firm performing the effort. If the SBIR effort leads to a truly disruptive technological innovation, functional design work may shift too far away from the user so that it becomes too costly to diffuse into the DoD. SBIR topic solicitations should be developed to find a satisfactory compromise of complexity. An ideal topic solicitation sits above a minimum level of stickiness to allow the user to make utility out of the product and falls under a maximum level of stickiness to encourage proper development of an innovative solution.

2.2.9 Innovation Valley of Death

The innovation valley of death comprises the loss of interest and therefore funding of an innovation that occurs over time. After an innovation is created, the interest from capital sources such as venture capitalists starts to languish. During this time, the cost of capital to develop the innovation into a commercial product also increases, which also increases the investment risk of failure. The combination of the growing lack of interest, development costs, and investment risks leads to the redundancy of an innovation and a failure to commercialize.

Auerswald and Branscomb (2003) investigated the innovation commercialization process with special attention on the causal factors that deter private investment in early-stage technology development. They found that the valley of death consists of a Darwinian ecosystem with business and technical ideas, big and small, competing for commercial success. They argue that it was government and large firms, rather than venture capitalists, involved with financing new technology, stating that technology push and pull policies are essential to assist the transition. The SBIR program provides a push policy that levels the playing field for small firms with small ideas competing within the ecosystem.

2.3 National SBIR Program

"The mission of the SBIR program is to support scientific excellence and technological innovation through the investment of Federal research funds in critical American priorities to build a strong national economy" (U.S. Small Business Administration, 2019). The program's explicit goals are to stimulate technological innovation, meet Federal research and development needs, foster and encourage participation in innovation and entrepreneurship by women and socially or economically disadvantaged persons, and increase private-sector commercialization of innovations derived from Federal research and development funding. The National SBIR program is managed by the United States Small Business Administration (SBA) that shapes the SBIR program following executive and legislative policies.

Today's SBIR program can trace its roots to the National Science Foundation's (NSF) SBIR program founded in 1977 (Small Business Administration, 2017). An NSF senior program officer envisioned a 3-phase structure to foster Research and Development (R&D) in high-tech businesses and push them to realize commercial potential. One of those NSF SBIR firms from 1977 discovered the cystic fibrosis gene and completed the Human Genome Map in 2003 (National Human Genome Research Institute, 2019). In 1979, the Small Business Administration concluded that SBIR programs should be instilled in all government agencies that involve research. President Ronald Reagan agreed with that conclusion and signed the Small Business Innovation Development Act in 1982 to establish a government-wide SBIR program.

2.3.1 Executive and Legislative-Level Policy

The Office of the President and Congress have guided the SBIR program from infancy to today. United States Code (USC), Title 15, Chapter 14A establishes the SBIR program following the Small Business Innovation Development Act of 1982 (United States Congress, 2011). Executive Order (EO) 13329, signed by President George W. Bush in 2004, requires SBIR agencies to give high priority to manufacturing-related research and development (Office of the President, 2004). The Fiscal Year (FY) 2012 National Defense Authorization Act (NDAA) extends and modifies the SBIR statute in USC, Title 15 (United States Congress, 2012). The FY 2012

NDAA created new directives for the DoD, to include reporting both the number and percentage of SBIR programs that transition into programs of record or fielded systems.

2.3.2 Small Business Administration Policy

The U.S. Small Business Administration (SBA) sets forth guidance to participating federal agencies for the general operation of the SBIR program. The SBA's SBIR Policy Directive requires that each SBIR agency make awards for federally-funded research or research and development (R/R&D) through a uniform, three-phase process (Small Business Administration, 2014). The standard SBIR process consists of three contracting phases that span from project feasibility (Phase I) to development of a prototype (Phase II) and subsequent development of that prototype into a commercial solution (Phase III) as shown in Table 1.

Table 1. SBIR Program Phase Overview (U.S. Small Business Administration, 2019)

Contracting Phase	Objective	Award Amount	Contract Duration
Phase I	Concept Development	Up to $150,000	6 Months
Phase II	Prototype Development	Up to $1,000,000	24 Months
Phase III	Commercialization	No SBIR Funding	Not Applicable

The objective of Phase I is to determine, as much as possible, the scientific and technical merit and feasibility of ideas that appear to have commercial potential. Contracts are typically awarded up to $150,000 over a span over six months. The SBA’s current SBIR Policy Directive requires an annual program solicitation for each participating agency. This solicitation sets a substantial number of Research or Research and Development (R/R&D) topics and subtopic areas consistent with stated agency needs or missions for SBIR program participation. They must describe these needs in "sufficient detail to assist in providing on-target responses, but cannot involve detailed specifications to prescribed solutions of the problems" (Small Business Administration, 2014). These SBIR topics will become the subject of technological advancement that each Small Business Concern (SBC) will apply for SBIR funding to develop. This relationship will prove useful when attempting to apply the categorization methods discussed later in this chapter to the methodology of this research effort.

The objective of Phase II is to develop SBIR efforts from Phase I that meet SBIR program needs and exhibit potential for commercial application. Contracts are awarded up to $1 million and usually span 24 months. Technologies under this phase of the SBIR program begin to enter a SBIR-specific microcosm of the innovation valley of death where SBIR program funding ends and commercial non-SBIR funding is required. Several participating agencies such as NASA and the DoD have created additional Phase II extension/enhancement programs to combat that issue by extending Phase II funding with non-SBIR (commercialization) and limited matching SBIR program funding (Department of Defense Office of Small Business Programs, 2018; NASA SBIR/STTR, 2018). The DoD Phase II Enhancement program will be discussed later in this chapter.

The objective of Phase III is the transition of SBIR research and technology from Phase II SBIR funding to Phase III commercial funding. This phase, otherwise known as commercialization, is the overall goal of the SBIR program and identifies that the SBIR-sponsored research or technology is of interest outside the SBIR program as continuing research or a tangible product. This phase is unique from the previous two SBIR phases in that it consists entirely of non-SBIR funding. The SBA SBIR policy aligns with the Bayh–Dole act of 1980, which states that firms participating in federally funded research are permitted to pursue ownership of innovations in preference to the government (Government Procurement Office, 2018). The policy explicitly states that a program is commercialized if it meets one of the three following criteria: commercial application of SBIR-funded research or technology financed by non-Federal sources, SBIR-derived products or services with the intended use by the Federal Government such as a Government Services Administration supply item or acquisition program of record, or continuation of an R/R&D effort funded by non-SBIR Federal funding sources (U.S. Small Business Administration, 2014).

2.3.3 SBIR Comparison to the STTR Program

Both the SBIR and STTR programs fall under the Small Business Administration and share similar participating government agencies such as the DoD and Department of Energy. While the SBIR program awards grants solely to small businesses, the STTR program awards grants to partnering small businesses and non-profit research institutions such as universities. The current SBA STTR Program Policy Directive states that for both Phase I and Phase II of the STTR effort, "not less than 40 percent of the [research or research and development] work must be performed by the SBC, and not less than 30 percent of the R/R&D work must be performed by the single, partnering Research Institution" (Small Business Administration Office of Investment and Innovation, 2014). The policy directive further requires that an agreed upon allocation of intellectual property rights and the rights to follow-on research, development, or commercialization be established between the SBC and the partnering Research Institution. These partnerships and agreements do not exist within the context of the SBIR program.

2.4 Department of Defense SBIR Program

The DoD is the largest SBIR agency representing an annual research and development portfolio of over $986 million (mandated as no less than 2.9 percent of the FY 2015 DoD total extramural research budget of $34 billion as per SBA SBIR policy) across hundreds of SBIR sponsored small businesses in FY 2015 (DoD Department of Small Business Programs, 2019; U.S. Small Business Administration, 2015). The DoD's dominance in size to other SBIR agencies is obvious when compared by both funding obligations and the number of contract awards as shown in figures 5 and 6, respectively. The DoD SBIR program consists of 12 participating component organizations such as the Uniformed Services (e.g. Army, Air Force, Navy), Chemical and Biological Defense Program, Defense Advanced Research Projects Agency, Defense Health Agency, Defense Logistics Agency, Defense Micro Electronics Activity, Defense Threat Reduction Agency, Missile Defense Agency, National Geospatial-Intelligence Agency, and Special Operations Command. The lion's share of the DoD SBIR budget is shared by the Army, Navy, and Air Force as shown in figure 7.

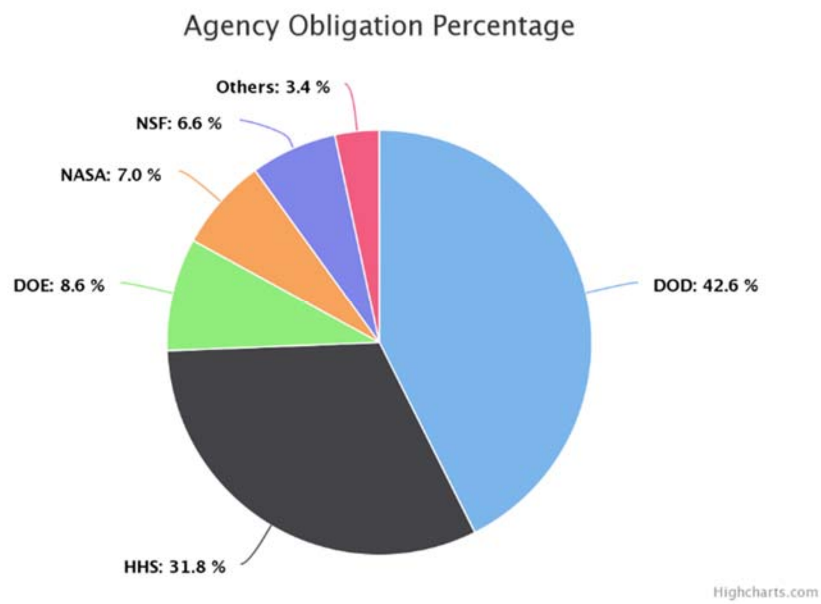

Figure 5. SBIR Agency Obligation Percentage for FY 2015 (U.S. Small Business Administration, 2018)

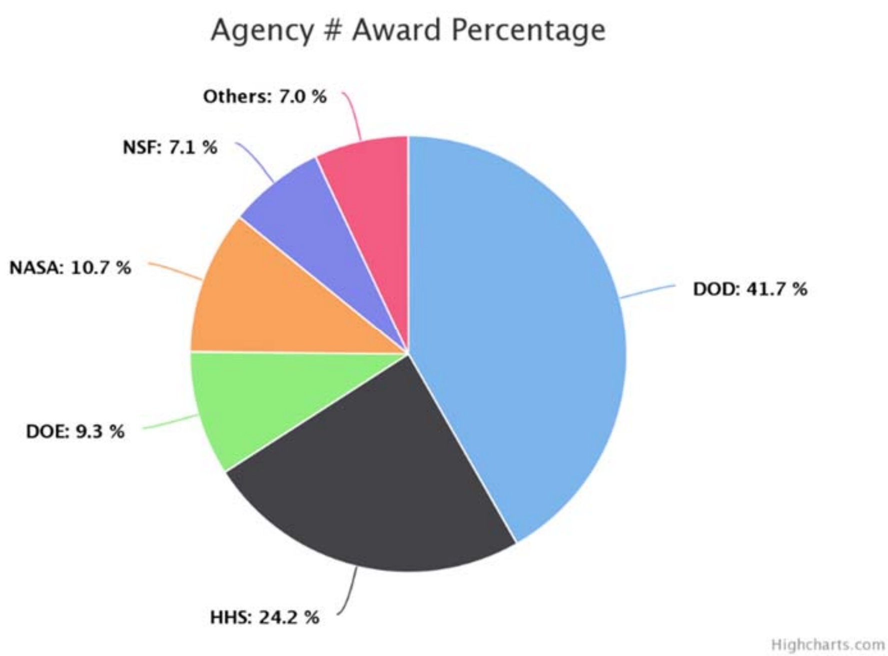

Figure 6. SBIR Agency Number of Award Percentages for FY 2015 (U.S. Small Business Administration, 2018)

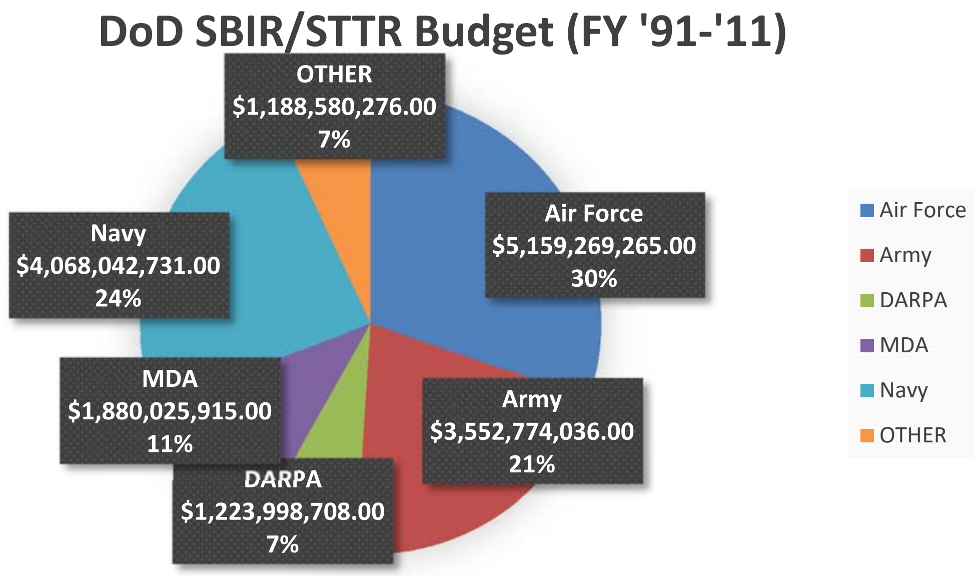

Figure 7. DoD SBIR/STTR Budget by Agency, Fiscal Years 1991 to 2011 (Department of Defense, Office of Small Business Programs, 2019; Department of Defense, Office of Small Business Programs, 2019)

2.4.1 DoD Policy

The DoD SBIR program operates under the governing policies established by the overarching SBA program; however, DoD Instruction (DODI) 5000.02: Operation of the Defense Acquisition System, provides guidance across DoD Acquisition to include sponsoring or managing organizations. Program managers are required to establish goals for applying SBIR technologies in programs of record and incentivize prime contractors to meet those goals. For contracts with a value at or above $100 million, program managers are required to establish goals for the transition of Phase III technologies in subcontracting plans and require primes to report the number and dollar amount of Phase III SBIR contracts (Under Secretary of Defense for Acquisition, 2017). DoD components are permitted to tailor their SBIR program to meet their needs, such as determining which types of research to pursue, what projects to fund, and how to monitor ongoing projects. DoD component-specific guidance further disseminates the DoDI in instructions such as Air Force Instruction (AFI) 61-102, SBIR and STTR programs.

2.4.2 Sponsoring and Managing Organizations

Each DoD SBIR contract consists of a sponsoring and managing organization. The sponsoring organization develops the initial research topics for solicitation and commits themselves to reasonably support the program in the commercialization phase. The managing organization serves as the technical expert; their role is to evaluate the SBIR contracts for validity and performance. An organization may serve as both a sponsor and managing organization. An example of the DoD SBIR sponsor and manager relationship is a stealth coating Phase II SBIR research program between the sponsoring F-22 program office of the Air Force Life Cycle Management Center (AFLCMC) and the managing Air Force Research Laboratory (AFRL) materials office. The AFLCMC program office would develop the solicitation topic and consult AFRL for technical evaluation of the contract's progress. After the contract has completed Phase II funding and met AFRL's evaluation criteria, the program office would provide Phase III funding to the SBIR contract to develop the technology for final acquisition.

SBIR sponsoring organizations are expected to provide follow-on Phase III funding to acquire the technology per SBIR Program and DoDI 5000.02 guidance. The sponsor's involvement with SBIR topic development indicates that a need exists for that technology. That need and the subsequent decision to provide funding can be influenced by several factors such as performance requirements, availability of funding, and remaining capability need. If a SBIR contract is unable to obtain sponsor funding, or commercialize, the funds will have to come from another source, within the government, outside the government, or not at all.

2.4.3 Commercialization

Commercialization and more specifically, commercialization performance within a DoD component, is the focus of this research effort. The DoD SBIR program simplifies the SBA's commercialization criteria and identifies commercialization as when an effort is "funded by sources outside the SBIR program" (United States Department of Defense, Office of Small Business Programs, 2018); these sources can be from within the U.S. Government or the commercial industry. The DoD commercialized over $31 billion across the SBIR and STTR programs as of April 2011 (Department of Defense, Office of Small Business Programs, 2011). The percentage of commercialization dollars shown in Figure 8 depict that the uniformed services of the DoD contribute a significant portion of the Department's commercialization dollars and are closely matched in doing so. The proportional similarity of commercialization dollars (23-26% of DoD commercialized dollars) resembles the budget similarities identified in Figure 7 (21-30% of the DoD contributions). These similarities support the possibility that the commercialization performance (commercialization rate) found for the Air Force during this research effort may closely compare to the rates of the Army and Navy.

Phase II efforts can be subject to a loss of interest over time; these efforts can eventually stagnate after Phase II funding. This issue is known to the SBIR program. Several DoD commercialization assistance initiatives have been developed to avoid this conundrum, such as the Phase II Enhancement (Phase II+), Commercialization Readiness Programs (CRP), and Transition Coaching programs. These initiatives, as depicted in Figure 9**,** help bridge the gap from Phase II to Phase III by injecting additional Phase II funding, business coaching, and networking opportunities.

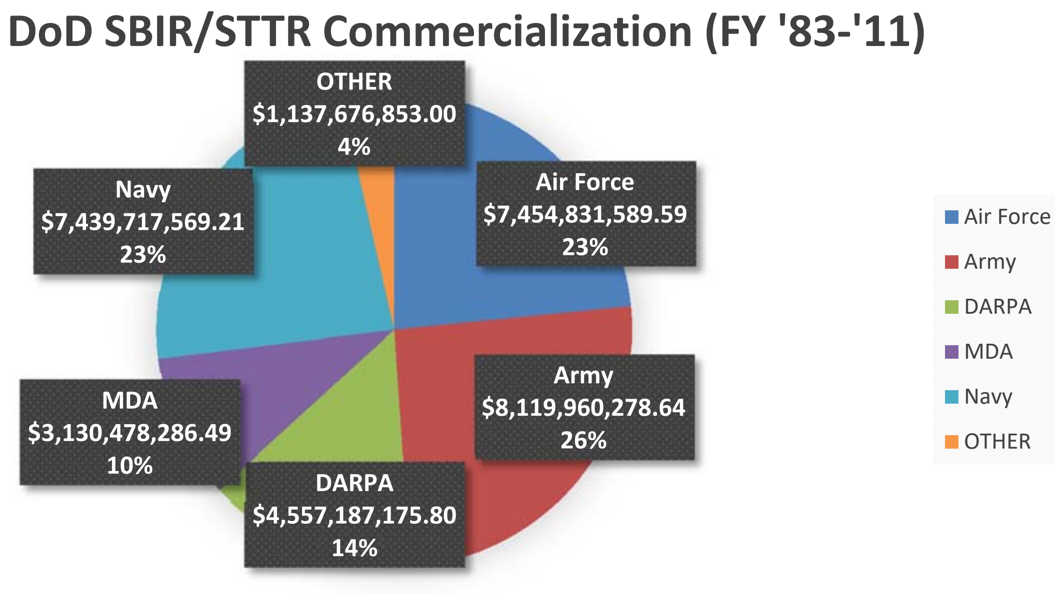

Figure 8. DoD SBIR/STTR Commercialization by Agency, Fiscal Years 1983-2011 (in billions) (Department of Defense, Office of Small Business Programs, 2011)

2.4.4 Commercialization Reporting

SBIR agencies and firms participating in the SBIR program are required to report commercialization information related to SBIR Phase II efforts (U.S. Small Business Administration, 2014). SBIR agencies are required to collect commercialization data from Small Business Concerns participating in the SBIR program and either maintain their commercialization database or forward that data to the SBA's centralized commercialization database. The SBA SBIR policy directive requires that each Phase I and Phase II applicant provide SBIR related data to include non-SBIR sales and investment data (U.S. Small Business Administration, 2014). Phase II awardees are required to submit commercialization data to the SBIR agency commercialization database upon completion of the last deliverable of the Phase II contract and are requested to voluntarily provide annual commercialization updates for a minimum period of 5 years after that.

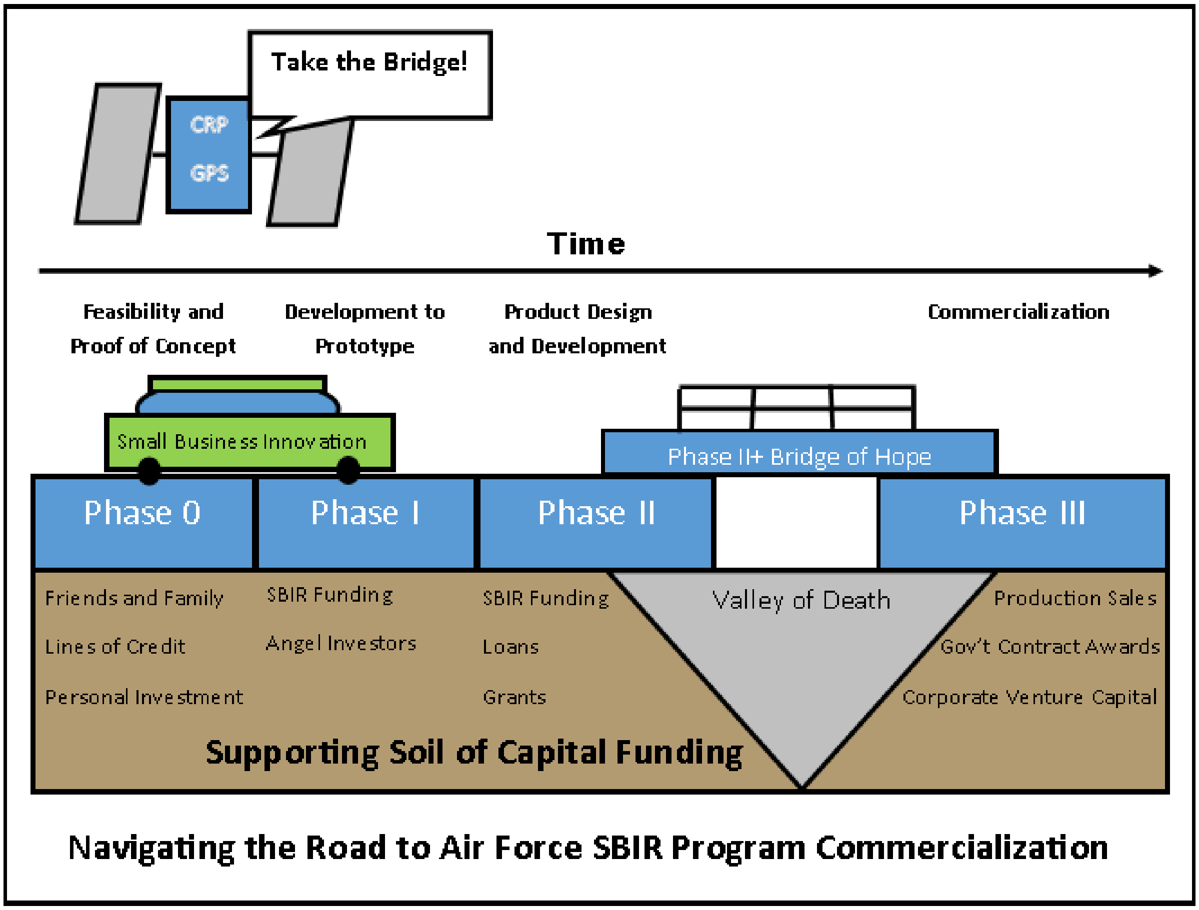

Figure 9. The Road to Air Force SBIR Program Commercialization

The DoD SBIR program maintains its centralized Commercialization Database on the DoD SBIR/STTR Small Business Portal. SBIR firms completing Phase II contracts within the DoD SBIR program can create and update a Company Commercialization Report (CCR) for their Phase II project on the DoD SBIR/STTR Small Business Portal. The CCR provides sales and additional investment data "resulting from, extending, or logically concluding the Phase II project" (DoD, Office of Small Business Programs, 2019). This data set was incorporated into this research to help determine Phase II SBIR contract commercialization.

The data set has known issues that were brought into question by multiple GAO reports (U.S. Government Accountability Office, 2014; U.S. Government Accountability Office, 2013).

GAO concerns note that the CCR does not capture all commercialization data and that the self-reporting nature of the reports can pose reliability and completeness challenges due to the potential of misreporting. An assumption is made to trust that the company reported rates are accurate or in any event would be underreported, resulting in a lower commercialization rate than actual. However, in subsequent future research of a focused portfolio of SBIR programs such as space or sustainment, more in-depth investigations occur to verify the commercialization data.

2.4.5 SBIR Valley of Death

The SBIR program provides funding to help small business developed technologies avoid the innovation “Valley of Death”; however, SBIR programs face their own SBIR-specific risk of attrition. This gap of diminishing interest and lack of capital funding, or the "SBIR Valley of Death," occurs for SBIR programs in the transition between Phase II SBIR funding and Phase III commercialization. According to the United States Institute of Electrical and Electronic Engineers (IEEE-USA), “many firms that complete Phase I and Phase II programs encounter the so-called Valley of Death funding gap to commercialization” (Institute of Electrical and Electronic Engineers, 2017). In order to bridge the "Valley of Death," the IEEE-USA recommends that the SBIR program should improve commercialization possibilities by authorizing experiments with funding beyond Phase II, such as Phase II Enhancement programs. These experiments help reduce the risk of reverting mature technologies identified by Utterback (1996).

2.4.6 Phase II Enhancement Programs

The Phase II Enhancement Program is a DoD initiative to “encourage the transition of SBIR research into DoD acquisition programs as well as the private sector” (U.S. Department of Defense Office of Small Business Programs, 2019). This initiative awards a SBIR effort a contribution that matches a non-SBIR investment up to $500,000 beyond the funding of the existing Phase II contract. Phase II Enhancement Programs extends the Phase II contract up to one year and are independently developed by each DoD component such as the Air Force (Phase II+) and Navy (Phase II.5) programs.

2.4.7 Commercialization Readiness Programs

The Commercialization Readiness Program (CRP) is a DoD initiative and part of the SBIR and Small Business Technology Transfer (STTR) Reauthorization Act of 2012 (Under Secretary of Defense for Acquisition, 2015). This program accelerates the transition of SBIR and STTR funded technologies to Phase III with specific emphasis to those that lead to programs of record and fielded systems. The CRP is the bridge between SBIR firms and the DoD, conducting activities that enhance the connectivity among SBIR firms, prime contractors, and the DoD science and technology and acquisition communities. As shown in figure 10, the CRP follows the SBIR effort from cradle (Phase 0) to commercialization (Phase III) and is independently operated by each DoD component.

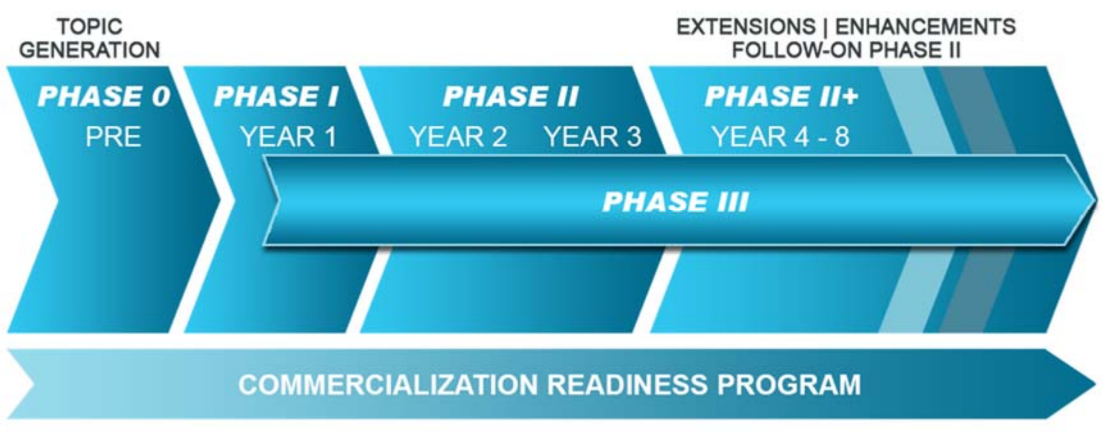

Figure 10. AF SBIR Program Phase Overview (Air Force SBIR/STTR Program, 2018)

The Air Force CRP focuses on topic alignment with Portfolio Executive Offices (PEOs) and identifying and verifying the customer, need, and technology (United States Air Force SBIR Office, 2017). Annual technology interchange meetings are held with major defense contractors to facilitate SBIR technologies that meet their needs. Small business industry days are facilitated for centers and PEOs. Technology transition plans and SBIR technology maturation plans are developed with SBIR firms for their projects.

The Army Commercialization Readiness Program assesses and identifies SBIR projects and companies with high transition potential that meet high priority requirements, thereby matching SBIR companies to customers and facilitates collaboration (United States Army SBIR, 2017). The CRP supports development of detailed technology transition plans and agreements. A CRP investment fund was developed to provide additional funding to outstanding Phase II projects to accelerate transition and commercialization.

The Navy Commercialization Readiness Program created Phase II.5 funding for Navy SBIR programs (United States Navy, 2017). Phase II.5 is comprised of 20% of each Navy System Command's SBIR funds with the intent of further developing SBIR technologies and to accelerate transition for existing Phase II projects. Phase II projects with awards that exceed $1 million or 24 months of performance will become a Phase II.5. The SBIR project must address a Navy need and be relevant to a planned/existing program of record or meet an identified technology gap. Phase II.5 projects are required to provide an annual project review, a quarterly report, and a technology transition plan or technology transition agreement as per the corresponding system command.

2.4.8 Transition Coaching Programs

The Air Force and the Navy conduct transition assistance programs in addition to the CRP with the intent of providing business training, advice, and networking opportunities. The Air Force Technology Acceleration Program (TAP) is an 18-hour course that takes SBIR firms with technology that has not been brought to or developed for the commercial market and provides training and demonstrations on how to conduct market assessments and develop commercialization plans (Air Force Research Lab, 2017). The goal of the program is to assist SBIR companies to move their technology from a research phase to a commercial solution.

The Navy Transition Assistance Program is an 11-month program with about two-thirds of Phase II recipients participating (United States Navy, 2017). The program provides a consulting service focused on improving SBIR firms' abilities to transition SBIR products. Profiles are developed for each participating firm's SBIR project and utilized in an annual Navy Opportunity Forum Conference to matching participants with direct exposure and opportunities to interact with government and industry transition partners.

2.5 Categorization Methods

The SBIR program awarded 4,324 new SBIR awards in Fiscal Year 2015. The focus of our research, the Air Force SBIR program, awarded over 670 SBIR awards in Fiscal Year 2013 (DoD Office of Small and Disadvantaged Business Utilization, 2018). To effectively conduct an empirical analysis of this data set, the utilization of categorical data is essential. The process of categorization "helps us to gain an understanding of the data source" (Miller, 2017) and has been described in multiple published works of data analysis (Baesens, 2014; Dean, 2014; Miner, et al., 2012).

Several sources of categorical data are available that provide utility for this analysis effort. The data itself can provide explicit and non-explicit forms of categorical data but may require further refinement to become usable. Multiple DoD taxonomies provide a legitimate framework of categorical data for a DoD-specific analysis that may apply to the SBIR program. Outside of the

DoD, NASA shares similar mission sets to the Air Force and has their own SBIR taxonomy approach.

2.5.1 Content Categorization

While seeming like a natural source of available categorical data, it should be stated that several methods of content categorization are available for analysis. The most accessible and most intuitive form of content categorization data would be a well-defined set of categorical data from an established taxonomy. While this is the preferred course of action, a data set is often full of inaccuracies, incompleteness, and inconsistencies that can corrupt a categorical analysis. The SBIR data used within this research effort is the product of inputs from both the Air Force SBIR program office and SBIR firms under the SBIR contract. Data inputs subject to multiple viewpoints and multiple standards for entry can create inconsistencies that require additional measures to correct the data set.

2.5.2 Acquisition and Supply Taxonomies

The DoD uses several standard government codes for contractors and equipment when conducting acquisition and supply functions. The DoD SBIR program maintains both North American Standard Industrial Code (NAICS) and Standard Industrial Classification (SIC) information of participating firms. The NAICS taxonomy is "the standard used by Federal statistical agencies in classifying business establishments for the purpose of collecting, analyzing, and publishing statistical data related to the U.S. business economy" (United States Census Bureau, 2019). The system was developed by the Office of Management and Budget in 1997 and was intended to replace the SIC code system. The system consists of 6-digit industry codes that are spread across 20 different industry sectors. The SIC taxonomy consists of 4-digit industry codes that indicate the company's type of business; it is used by the U.S. Securities and Exchange Commission when reviewing company filings (U.S. Securities and Exchange Commission , 2019).

The Government Services Administration System for Award Management (SAM) database maintains data on firms that conduct business with the United States Government such as the SBIR program. The SAM database maintains standard business information as well as NAICS and Product and Service Codes (PSC) data. The Defense Acquisition University defines the PSC taxonomy as "a four-digit code used by all federal government contracting activities for identifying and classifying the services and Supplies & Equipment (S&E) that are purchased under contract" (Defense Acquisition University, 2018). In August 2012 the Office of the Undersecretary of Defense for Acquisition, Technology, and Logistics released a memo that recommended the DoD use a taxonomy that maps PSCs to "facilitate collaboration within the acquisition workforce and with customer organizations" (Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, 2012).

2.5.3 Capability Based Taxonomies

The SBIR program develops functional requirements which small businesses apply for contracts to develop into a form (e.g., an actual physical system). These functional requirements provide capabilities to the end user. Being able to match capabilities directly to the Air Force SBIR program could provide better representation to the DoD. Two capability-based taxonomies provide possible avenues of fulfilling this match: the DoD Joint Capability Areas (JCAs) and the National Air and Space Administration (NASA) SBIR/STTR taxonomy.

The JCAs represent current capabilities that are required or desired from within the DoD. The taxonomy consists of eight first-tier primary categories that are decomposed to the third or fourth tier. These capability categories are the product of decomposing DoD capabilities into functional or operational lines and favored functional categories. "Functional categories minimize redundancies in capability decomposition, provide clearer boundaries to assign weapon systems, and improve management ability to develop and implement capabilities planning" (DoD Joint

Chiefs of Staff, J-8 Force Structure, Resources, and Assessment Directorate, 2019). The JCAs were officially created and approved in 2006; subsequent refinements were completed in 2014 and 2018. A complete list of the JCAs and their definitions can be found in Appendix A.

The NASA SBIR/STTR Taxonomy is part of the SBIR program solicitation process and is assigned by the NASA SBIR program to SBIR topics. The taxonomy consists of space-centric capabilities and represents what NASA expects to see from their SBIR program. Any work on a SBIR effort should fall within that respective topic's taxonomy. A comprehensive list of the NASA SBIR taxonomy can be found in Appendix B.

Both the JCA and NASA SBIR taxonomies consist of desired capabilities for their respective agencies. The Air Force is unique in that it is the only DoD, and rather only federal, SBIR agency that conducts air and space mission sets that directly relate to NASA operations. Aligning both SBIR efforts provides a unique cost and effort sharing opportunity. To demonstrate the feasibility of this concept, the respective taxonomies should be interconnected. An example of the alignment between DoD and NASA taxonomy is shown in figure 11 (a full mapping to the 2nd Tier can be found in Appendix C); all but one JCA and one NASA SBIR taxonomy field were able to be matched. The AF SBIR taxonomy should, at least conceptually, derive benefit from a combination of both taxonomies.

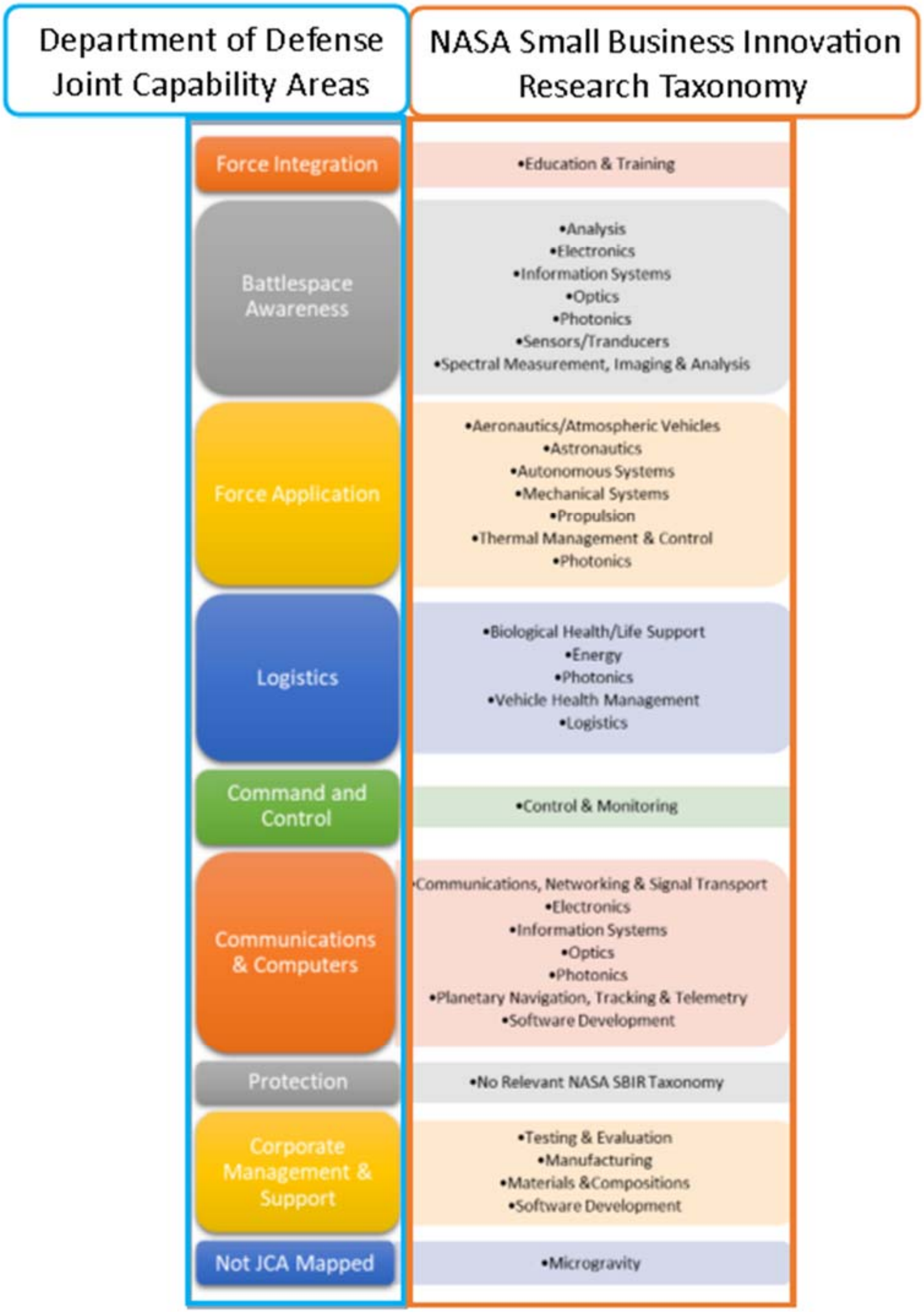

Figure 11. Mapping DoD Joint Capability Areas (1st Tier) to NASA SBIR Taxonomy Topics to demonstrate alignment between the DoD and NASA SBIR Technologies

2.6 Summary

Innovation creates a unique environment for the DoD SBIR program to operate. Each service has its own approach to navigating the valley of death in order to secure radical innovations for the warfighter. The current measure of success, commercialization, meets the national objective of the SBIR program. The relatively large nature of the SBIR program indicates the need for proper categorization methods to analyze AF SBIR commercialization performance adequately. Several relevant taxonomies exist within the DoD and outside SBIR agencies such as NASA. Christensen (2016) warned that an organization's capabilities define its disabilities and that a disruptive innovation should require a "unique new set of capabilities". The proposed AF SBIR taxonomy will need to build upon the DoD JCA taxonomy of current needs and inject future and shared needs as shown in figure 12 to meet and exceed the battlespace of tomorrow.

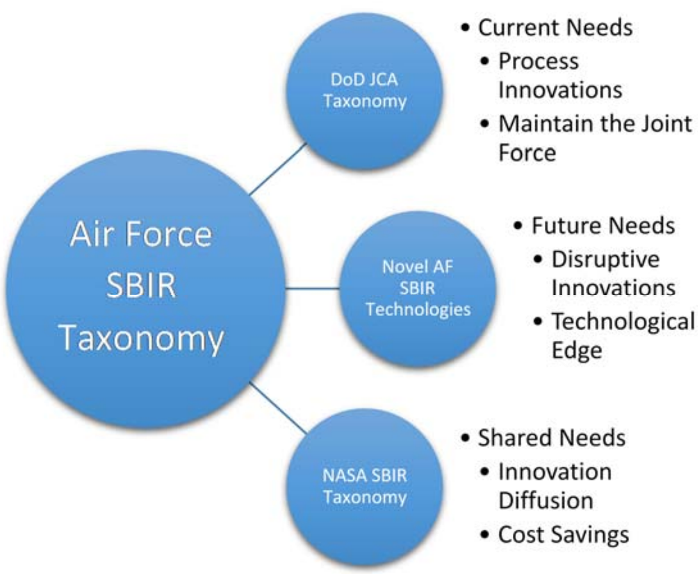

Figure 12. The Optimal Air Force SBIR Taxonomy

III. Methodology

3.1 Chapter Overview

This research effort will be conducted in three analysis phases: 1) an initial statistical analysis of SBIR phase II program commercialization performance, 2) an additional statistical analysis of commercialization performance with available categorization data, and 3) a final statistical analysis of commercialization performance with a developed set of categorical data (taxonomy). These processes and their mapping to the established research questions are shown in Table 2.

This research is motivated by the need to understand Air Force SBIR program commercialization. Current literature and available information lack a valid capability-driven taxonomy that applies to Air Force, or Department of Defense (DoD) Small Business Innovation Research (SBIR) programs. This gap significantly impacts the ability to provide a thorough analysis of commercialization performance and must be rectified. This chapter will explain in detail the methods described in Table 2..

Table 2. Research Overview

Research Overview with Question to Method Mapping	
Research Question	**Research Method**
What is the commercialization performance of Air Force SBIR Programs?	Create SBIR Dataset of Phase II and Commercialization (Phase III) Report Data
	Clean Data (Corrections and Exclusions)
	Analyze Data for Commercialization Performance
What unique behaviors or patterns demonstrated within that commercialization performance?	Analyze Current Categorical Data within SBIR Dataset for Commercialization Performance Trends
What methods can be developed to investigate and explain those behaviors and patterns?	Develop Categorical Data (Capability-Based Taxonomy)
	Verify Taxonomy (Inter-Rater Reliability)
What specific SBIR technologies of interest identified by those methods?	Apply Categorical Data (Taxonomy) to SBIR Data Set
	Analyze Developed Categorical Data within SBIR Dataset for Commercialization Performance

3.2 Research Method

Empirical methods have been selected to test the assumptions established within the literature and provide further investigation when observations challenge those assumptions. Qualitative analysis dominates most of this research effort and is the product of existing data, derived from DoD SBIR databases and used to measure commercialization performance. Qualitative analysis “[brings] a new or fresh perspective to existing research in areas that have been dominated by quantitative methods” (Weathington, Cunningham, & Pittenger, 2012); it is used to enhance the existing dataset through the development of new constructs and categorical data. This development will require the application of existing relevant taxonomies into a tailored qualitative framework applicable to DoD SBIR programs.

3.3 Research Setting

This research considers Phase II SBIR programs with closed contracts reported during DoD Fiscal Years 2015 through 2018 (as of July 2018). These programs consist of state of the art technologies designed for the current and future needs of the Air Force. This selection is made for several reasons. First, the commercialization of SBIR programs has been identified as an area of concern by multiple SBIR agencies (U.S. Department of Defense Office of Small Business Programs, 2019; U.S. Department of Energy Department of Science, 2019; National Institute of Health, 2019). Second, Phase II programs with closed contracts are no longer provided SBIR program funding and are subject to the "SBIR Valley of Death", thus making "it difficult to identify funding in a manner that supports timely insertion of the SBIR technology" (United States Department of Defense, Office of Small Business Programs, 2018). Finally, the research timeline of Fiscal Year 2015 to present (July 2018) has two benefits: 1) it coincides with the arrival of incoming leadership at the Air Force SBIR program office, thus controlling for effects from leadership changes; 2) it allows for follow-on interviews. Although human memory reliability degrades over time, the selected timeframe is recent enough to maintain accurate memories of key informants in the Air Force SBIR program office or any SBIR firms.

3.4 Data Collection

Data was collected for Air Force SBIR Phase II programs, Air Force SBIR Program Company Commercialization Reports (CCRs), DoD SBIR Topics, and any relevant categorization taxonomies within the Department of Defense or any other government agency. The Air Force SBIR Phase II program data set serves as the overarching host data set for analysis. All other data generated or pulled from other sources are compiled into the Air Force SBIR Phase II program data set. A comprehensive list of all data retrieved and a reference to their respective sources is located in Table 3.

Table 3. Research Data Sources

Data Sources		
Data Type	Organization	Location
AF SBIR Phase II Program Reports (FY15-Jul 18)	Department of Defense	https://sbir.defensebusiness.org
AF SBIR Company Commercialization Reports (FY15-Now)	Department of Defense	https://sbir.defensebusiness.org
SBIR Firm Data	U.S. Government Services Administration	https://www.sam.gov/SAM/
DoD SBIR Topics (All Years)	Department of Defense	https://sbir.defensebusiness.org Contact website helpdesk (1-800-348-0787) for data pull.
Product and Service Codes	U.S. Government Services Administration	https://www.fpds.gov/downloads/psc_data_Oct012011.xls
North American Industrial Classification (NAICS) Codes	U.S. Census Bureau	https://www.census.gov/eos/www/naics/
Standard Industrial Classification (SIC) Codes	Securities Exchange Commission	https://www.sec.gov/info/edgar/siccodes.htm
NASA SBIR Taxonomy	North American Space Administration	https://sbir.gsfc.nasa.gov/sites/default/files/tech_taxonomy_0.pdf
DoD Joint Capability Areas	Department of Defense	https://intellipedia.intelink.gov/wiki/Joint_Capability_Areas

3.5 Data Analysis

This section will provide the steps taken to analyze commercialization performance, identify unique behaviors or patterns, and identify any specific SBIR technologies of interest. The outcome of this analysis shall provide the basis for recommendations to the Air Force SBIR program office to improve the commercialization performance of SBIR programs.

3.5.1 Data Set Creation and Cleaning

The first step in the analysis is assembling the data set and correcting the data set for errors or missing data that could negatively impact commercialization analysis efforts. Duplicate data sets and data sets that are missing adequate contract or date data to determine Phase II contract closeout were excluded from analysis. Open contracts that still receive SBIR Phase II funding were excluded from analysis. Contract funding data will be subject to the SBIR funding cap of $1,093,015 Phase II + $163,952 funds with an allowance of a 50% increase (this increase includes programs such as the DoD Phase II Enhancement Programs outlined in Chapter II) over that amount as per SBIR policy (U.S. Small Business Administration, 2014); contracts exceeding that cap were excluded from funding analysis.

3.5.2 Commercialization Performance Analysis with Current Data

A quantitative commercialization performance analysis is possible following corrections and exclusions of the data set. Existing categorical data within the data set is the independent variable for each commercialization performance analysis. Program commercialization (commercialized versus non-commercialized) is the dependent variable for all commercialization performance analysis. The ratio of commercialized to non-commercialized programs is identified for the entire set and for subsets (categories).

Existing categorical data within the data set derives from the original Phase II program report, including cross-references to SBIR firm data, SBIR topic data, and baseline taxonomy data. These categories allow commercialization performance comparisons. The dependent variable is commercialization and relative performance of categories is considered for trends. This phase of analysis sought unique or interesting behaviors and patterns. The presence of coherent behaviors and patterns determines the viability of existing categorical data; if randomness is depicted by the analysis (no unique or interesting behavior or pattern can be deduced), the categorical data set was not considered viable.

3.5.3 Categorical Data Development and Verification

The examination of current literature identified the lack of a tailored capability-driven taxonomy for DoD SBIR programs. The existing categories are complemented with the application of a capabilities-based taxonomy. The current capability-driven DoD Taxonomy, Joint Capability Areas (JCAs), was examined to determine its viability as an adequate taxonomy for Air Force SBIR programs. Analysis was conducted with a single rater and a panel of raters participating in a JCA assignment exercise. The single-rater JCA assignment exercise mapped the JCAs to samples of SBIR topics (>=20 SBIR topics) by the JCA mapping process outlined in Figure 14.

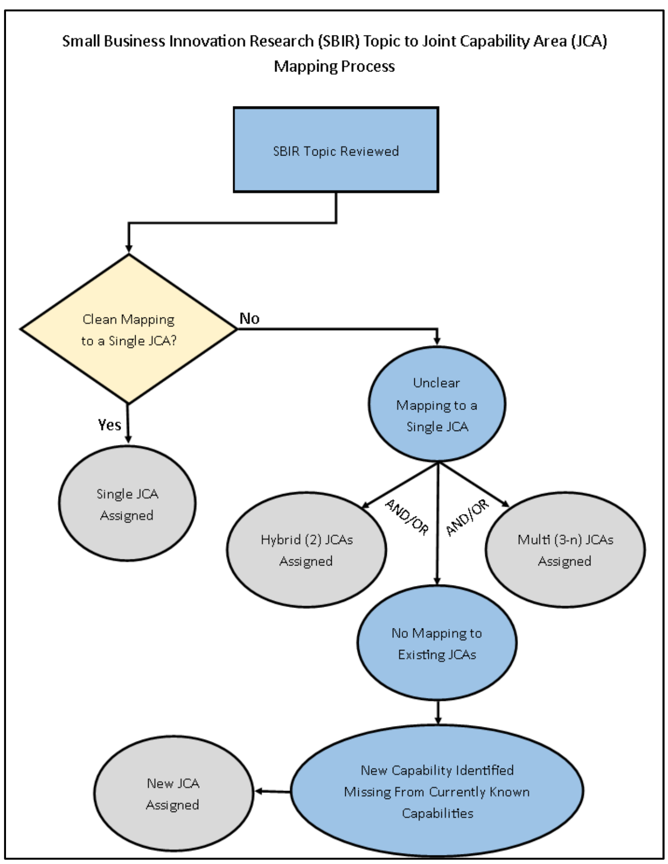

Figure 13. JCA Mapping Process

The single-rater JCA mapping exercise was conducted amongst the research team; this team consists of two individuals with more than 20 years of acquisition experience and three individuals with less than five years of acquisition experience. Several exploratory iterations of the single-rater assignment exercise were allowed to determine the feasibility and subsequent testing process improvements in determining interrater reliability. A final non-exploratory single-rater JCA assignment exercise was conducted in which results were compared and analyzed to determine interrater reliability. Interrater reliability was employed as a means to validate this mapping process.

Interrater reliability can be defined as:

> A statistical index that represents how well the records from multiple observers match. If the interrater reliability is high, we can place greater confidence in the data and proceed with [the] analysis. If the interrater reliability is low, analysis of the data may not be useful because the measurement error is too great. Low interrater reliability can indicate that the observers need to be better trained, that the definitions need to be clarified, that the recording procedure needs to be revised, or that some combination of these solutions may need to be used (Weathington, Cunningham, & Pittenger, 2012).

A common empirical method to measure interrater reliability is Cohen's Kappa (Cohen, 1968); this statistical value measures the agreement among multiple subjects for two raters. An updated empirical method, Fleiss' Kappa (Fleiss & Cohen, 1973), adapts Cohen's Kappa to testing the agreement among more than two raters and calculating the difference between observed agreement and the level agreement expected to be by chance. This research effort used a formulation of Fleiss' Kappa that was created for use-case rating agreement (Shoufan & Damiani, 2017). It is determined by the following equation:

$$K = \frac{\bar{P} - P_e}{1 - P_e}$$

Where K *(Kappa)* is the *level of agreement*, $\bar{P}$ is the *observed agreement*, and $\bar{P}_e$ is the *level of agreement by chance. Observed Agreement,* $\bar{P}$*,* is determined by:

$$\bar{P} = \frac{1}{N}\sum_{i=1}^{N} P_i$$

Where *N* is the *total number of SBIR topics* and P_i is the *observed agreement for the i-th SBIR topic*. *Observed agreement for the i-th SBIR topic*, P_i, is determined by:

$$P_i = \frac{1}{n(n-1)}\sum_{j=1}^{k}\left(n_{ij}^2 - n_{ij}\right)$$

Where *n* is the *total number of raters*, *k* is the *total number of JCA rating levels*, and n_{ij} is *the number of experts who assigned the i-th subject to the j-th JCA rating level*. The *level of agreement by chance*, $\bar{P}_e$, is determined by:

$$\bar{P}_e = \sum_{j=1} p_j^2$$

Where P_j is the *proportion of assignments to a JCA rating level* of *j*. Finally, the *proportion of assignments to a rating level*, P_j is determined by:

$$P_j = \frac{1}{Nn}\sum_{i=1}^{N} n_{ij}$$

Where N is the *total number of SBIR topics*, n is the *total number of raters*, and n_{ij} is the *number of experts who assigned the i-th subject to the j-th rating level.*

Our effort tested reliability on multiple ratings, for multiple topics (subjects), by multiple raters. The added variable of rating multiplicity requires a modification to the reliability test; three separate tests determined agreement. Reliability for JCA assignment was evaluated by a binary test of single versus multiple JCA assignment, a binary test of new capability (outside of the JCA taxonomy) identification, and a continuous test of the primary (best fitting) JCA for each SBIR topic. The results of the three tests were compared to the Kappa interpretation table developed by Landis and Koch (1977) shown in Table 4. Single rater assignment of JCAs were considered a valid measure if all three tests successfully met or exceeded the "Fair Agreement" threshold (>=0.21) shown in the table. If considered valid, all appropriate SBIR topics (referenced from the Phase II SBIR contract data set) would have been shared across the research team for complete assignment. If any of the three tests failed to meet that threshold, single-rater JCA assignment would be considered an invalid rating measure and a secondary method of JCA assignment would have been tested.

Table 4. Kappa Interpretation Table (Landis & Koch, 1977)

K	Interpretation
< 0	Poor Agreement
0.01 – 0.20	Slight Agreement
0.21 – 0.40	Fair Agreement
0.41 – 0.60	Moderate Agreement
0.61 – 0.80	Substantial Agreement
0.81 – 1.00	Almost Perfect Agreement

The second method of JCA assignment was by a panel of raters, working in the same room, and reaching majority concurrence (>50% agreement) on each topic. The research team from the previous JCA assignment exercise compromised the JCA rating panel and at least three members of the team were present for the assignment exercise. A representative sample of the applicable SBIR topic population was the subject of this JCA assignment exercise; sample size estimation followed the formula of Krejcie and Morgan (1970):

$$s = \frac{X^2NP(1-P)}{d^2(N-1) + X^2P(1-P)}$$

Where s is the *required sample size*, X^2 is the *chi-square value for 1 degree of freedom at the desired confidence level* (3.841 at a .95% confidence level), N is the *population size*, P is the *population proportion* (recommended by Krejcie and Morgan to be .50 for maximum sample size), and d is the *degree of accuracy* expressed as a proportion (recommended by Krejcie and Morgan to be .05). To allow ample time for assignment, the assignment exercise was broken up into two-hour assignment sessions with an allotment of 60 SBIR topics per session.

The validity of the panel-of-raters JCA assignment exercise was tested by using a binary test of debated versus non-debated topics of JCA assignment. A topic was considered debated if assignment takes longer than two minutes to complete during the exercise. Debate was notated next to each associated SBIR topic within the resulting list of assigned topics. The exercise was considered valid if less than 25% of SBIR topics within the sample were debated.

The nature of a rating panel brings about concerns of groupthink, or a concurrence-seeking tendency that leads groups to poor decision making (Janis, 1982). Several methods have been suggested to combat groupthink, such as encouraging authentic dissent among groups (Sunstein & Hastie, 2015), avoiding chasing the experts (Sunstein & Hastie, 2015), and encouraging diversity among groups (Greitemeyer, Schulz-Hardt, & Frey, 2009). To encourage dissent and active participation among the rating panel, an agreement ceiling was added. If 100% agreement (no dissent among JCA assignments) was found during the assignment exercise, modifications to the assignment exercise would have been required. To encourage diversity among the rating panel and to avoid "chasing the experts," participation in assignment sessions varied among the research team. Assignment exercise sessions were scheduled to the availability of at least three members of the research team and participant variation was noted.

3.5.4 Categorical Data Application and Commercialization Performance Analysis

If both individual and panel-of-raters JCA assignment methods were considered invalid, the JCAs would have been considered inapplicable for the Air Force SBIR program. If either JCA assignment was considered successful, the JCA assignment results would have been applied within the SBIR topic data set and referenced to each respective SBIR contract from which the SBIR topic was derived. If only a sample of SBIR topics were assigned JCAs, the SBIR topics with unassigned JCAs as well as their respective SBIR contracts would have been excluded from commercialization analysis. The overall commercialization performance of non-excluded SBIR contracts was calculated. Analysis efforts of commercialization performance by JCAs was conducted at both the second and third JCA tier.

A comparison of SBIR contract commercialization was conducted by the verified categorical method (existing data or JCA assignment). An “apples-to-apples” comparison of categorical groups was desired to mitigate any effects of Simpson’s Paradox, or a disproportionate allocation of a response variable among categorical groups that results in an erroneous determination of association (Ameringer, Serlin, & Ward, 2009). An exclusion and simulation analysis was conducted on the categorized data to account for the paradox. Any grouping with a population below three SBIR contracts was excluded from analysis. Any grouping with a population above three SBIR contracts was bootstrapped to a population of three by random sampling of simulations. A random sampling of three SBIR contracts, and their subsequent commercialization performance (commercialization rate), was simulated using 1,000 iterations. The average commercialization rate of all 1,000 iterations was used as that specific categorical group’s rate in comparison to other groupings. After all categorical groups are bootstrapped or excluded, a comparison of commercialization rates was conducted to determine any unique or interesting behaviors.

3.6 Summary

A three-phase analysis process was conducted to determine the commercialization performance of Air Force SBIR Phase II programs from FY15 to FY18 and to identify any unique behaviors within that performance. The analysis was both quantitative, using data from within the data set, and qualitative, developing categorical data to identify and explain unique behaviors of commercialization performance. If existing categorical data was insufficient, the DoD JCAs would have been explored as a possible avenue of approach. An analysis of commercialization between categorical groupings was conducted to identify groups that had a significant impact on SBIR contract commercialization performance. A depiction of the analysis, and the results of that analysis can be found in Chapter IV.

IV. Analysis and Results

4.1 Chapter Overview

The analysis conducted within this research effort consisted of establishing an Air Force Phase II Small Business Innovation Research (SBIR) data set and analyzing the data set to determine commercialization performance with the intent to identify any unique behaviors or areas of concern within that performance. New categorical methods were developed and applied to assist with commercialization analysis. The most viable categorical method will be applied to the data set, and the data will be reanalyzed for commercialization performance behavior. New and interesting commercialization trends will be identified as areas of interest for future research. Table 5 provides a brief overview of the analysis efforts described in this chapter with clear traceability back to the research method.

4.2 Data Set Creation

The SBIR Program data set consists of Air Force Small Business Innovation Research (SBIR) program data from Phase II reports and Phase III Company Commercialization Reports (CCRs). SBIR Topic and Department of Defense (DoD) taxonomy data were cross-referenced and applied to the SBIR Program dataset for categorical methods to supplement statistical analysis of commercialization performance. The program data within this set was current as of July 2018.

Table 5. Research Analysis Summary

Research Analysis Overview with Methodology Tracing	
Research Method	**Analysis of Steps Conducted**
Create SBIR Dataset of Phase II and Commercialization (Phase III) Report Data	Host data set created from the Air Force SBIR Phase II Program data.
	AF SBIR Company Commercialization Report (CCR) data integrated into data set.
	706 SBIR contracts within the data set.
Clean Data (Corrections and Exclusions)	80 SBIR contracts excluded for incomplete cost or date data. 100 SBIR contracts excluded for currency as a Phase II program (not closed).
Analyze Data for Commercialization Performance	526 closed SBIR contracts analyzed for commercialization performance.
	7.6% of SBIR programs were commercialized with Non-SBIR dollars.
Analyze Current Categorical Data within SBIR Dataset for Commercialization Performance Trends	Inherent categorical data such as existing data categories, contract categorization methods, and firm categorization methods was analyzed for significance to commercialization performance.
	The analysis had no coherent performance patterns; further categorical data development required.
Develop Categorical Data (Capability-Based Taxonomy)	DoD Joint Capability Areas (JCAs) identified as best available taxonomy for SBIR data set due to relevance and operational alignment.
Verify Taxonomy (Inter-Rater Reliability)	JCA mapping to SBIR topic exercises conducted on 20 sample SBIR topics as an individual effort among research team.
	Testing shows poor agreement among raters (<0.2 Fleiss kappa correlation significance) for two of three agreement tests.
	Additional mapping exercise conducted on 225 SBIR topic samples in a group panel format.
	Topics that arise debate among group panel recorded as disagreements among raters.
	Testing shows acceptable (97.4%) agreement among group panel of raters.
Apply Categorical Data (Taxonomy) to SBIR Data Set	225 SBIR topics were classified to single JCAs by the panel of raters.
	301 SBIR contracts were excluded from commercialization analysis due to a lack of SBIR topic JCA assignment.
	36 SBIR contract excluded from commercialization analysis during standardization of JCA category group populations.
Analyze Developed Categorical Data within SBIR Dataset for Commercialization Performance	178 SBIR contracts were analyzed resulting in a commercialization performance of 5.60%
	JCA areas cross-referenced with commercialization performance to identify areas of interest.

4.2.1 Phase II SBIR and Commercialization Data Compilation

Commercialization and Phase II SBIR program data was pulled from the DoD SBIR/STTR Small Business Portal for Fiscal Year (FY) 2015 to FY 2018. A complete data pull was done for CCR commercialization reports, and due to limits on the website, data was pulled for Phase II programs by each reporting year (FY15-18). Phase II SBIR program data from each FY were merged into an overall data set. The FY15-18 Phase II data set serves as the principal data set for commercialization performance analysis; all other data sets (e.g., government taxonomy and SBIR topic data) were included within this data set.

4.2.2 External Data Inclusions

Several data sets were pulled from external data sources outside of the DoD SBIR/STTR Small Business Portal. SBIR Firm Data was pulled from the System for Award Management (SAM) website. DoD and USG taxonomies were pulled from their respective sources. A comprehensive list of DoD SBIR Topics (1998-2018) was provided by the DoD SBIR/STTR Small Business Portal site administrators.

4.2.2 Data Set Issues and Analysis Exclusions

Duplicate SBIR program contracts were found within the data set due to the merging of multiple report year Phase II program data, and those duplicate values were removed. Contracts exceeding the SBIR funding cap of $1,885,450.50 were excluded from funding analysis. Contracts with incomplete cost (award amount and project cost) and date (contract award and contract end) data can be found within the data set. Contract closeout is determined by either fully expending awarded funds (project cost exceeds award amount) or exceeding the contract end date. Contract end dates can be determined from SBIR programs missing that data by calculation from listed contract start dates. SBIR Phase II Program data that fails to include adequate cost data or date data to determine Phase II contract closeout was removed from the analysis. The focus of this research is a commercialization analysis of AF SBIR programs which are no longer receiving Phase II SBIR funding; therefore, contracts that have not yet been awarded a Phase II contract were removed from the analysis.

4.2.3 Final Data Set for Analysis

The original data set contained 706 SBIR contracts which included missing/incomplete data. Eighty contracts were excluded from analysis for incomplete cost/date data and Phase II contracts that have not been awarded. One hundred contracts were excluded from analysis as outstanding "open" Phase II contracts that still receive SBIR program funding. The final data set contained 526 SBIR contracts that were analyzed for commercialization performance. A publicly available version of the final data set and data field descriptions is found in Appendix D and E.

4.3 Existing Categorical Data Analysis

An initial analysis was conducted with categorical data available within or efficiently generated from within the data set. These attempts included regression analysis using existing data categories, contract categorization, firm categorization, and SBIR topic classification. The results of these analyses were determined to be randomly distributed or insignificant in determining commercialization performance. These initial commercialization analysis attempts are described in Appendix F of this document.

4.4 Categorical Data Development and Verification

The existing categorical data failed to provide a significant relationship to commercialization performance. The research effort turned to the DoD Joint Capability Areas taxonomy as a possible means to categorize Air Force SBIR topics and subsequent SBIR Phase II efforts. The JCAs provide both relevance as a DoD taxonomy and operational alignment to desired DoD capabilities. Two forms of JCA assignment, single rater and a panel of raters, were conducted on samples of SBIR topics to determine reliability among raters. Either form of JCA assignment, if reliable, will be applied to a representative sample of SBIR topics.

4.4.1 Single Rater JCA Assignment

The research team conducted multiple single-rater JCA assignment exercises with differing samples of 20 SBIR topics. The research team conducted this exercise on an individual basis following the JCA assignment rules of engagement located in Appendix G. The research team rated each topic using three rating types: best fitting JCA, new capability or a new JCA, and if multiple JCAs applied. Three iterations of exploratory single-rater JCA assignment exercises were conducted; the results showed that interrater reliability testing is feasible.

A final non-exploratory single-rater JCA assignment exercise was conducted. The JCA assignment inputs of each rater and each rating type were subjected to Fleiss' Kappa to determine interrater agreement for best fitting single JCA, new capability identified, and multiple JCA applicability, respectively. The calculation, as shown in Appendix H, determined interrater agreement as 0.37 (fair agreement) for best fitting JCA assignment, 0.18 (slight agreement) for new capabilities identified, and -0.03 (poor agreement) for multiple JCA applicability. Due to two of three interrater reliability tests failing to meet the established threshold of 0.20 (fair agreement), a panel-of-raters JCA assignment exercise was conducted.

4.4.2 Panel of Raters JCA Assignment

A panel-of-raters JCA assignment exercise was conducted among members of the research team. Due to the time consuming nature of the assignment (more than 8 hours), the assignment exercise set a threshold of three or more research team members for a valid assignment panel. A representative sample of SBIR topics was calculated to be 225 topics as shown in Table 6, and were pulled by both serial (1-100 topics) and random (101-225 topics) selection. A serial selection was conducted due to an initial assumption of variation among each serial SBIR topic. It was determined during the initial assignment of 100 SBIR topics that these topics were most likely submitted in groupings by sponsoring organizations and consisted of similar subject matter. Random sampling was conducted on the next 125 topics from the SBIR topic data set to represent the population best.

The JCAs were assigned based on a majority rule principle; however, the research team met an impasse, or argument, six times or just over 2.6% of the 225 topics that were assigned. Both the assignment floor (>= 75% agreement) and ceiling (> 0% dissent or argument) were met. The JCA assignment exercise was conducted in four, two-hour assignment sessions. Rater panel membership varied during each session, with sessions consisting mainly of experienced and unexperienced personnel respectively.

A list of the sampled SBIR topics and their corresponding assigned JCAs is provided in Appendix I. The general logic used by the research team during the JCA assignment process is located in Appendix J. The JCAs were assigned down to the third tier with the exception of SBIR topics where the capabilities identified spanned outside the boundary of a single third-tier JCA; in that event, the second-tier JCA was assigned for that capability and subsequent SBIR topic.

Table 6. SBIR Topic Sample Size Estimation for JCA Assignment (Krejcie & Morgan, 1970)

SBIR Topic Sample Size Estimation for JCA Assignment	
$s = \frac{X^2NP(1-P)}{d^2(N-1)+X^2P(1-P)}$	
x^2	3.841
N	537
P	0.5
d	0.05
s	224.1731334

4.5 Categorical Data Analysis

Both existing and new categorical methods were tested for applicability and validity to the Air Force SBIR program. Existing categorical data proved insignificant in determining commercialization behavior among the SBIR contracts. The JCA taxonomy paired with a panel of raters assignment methodology was proven to be the most applicable by addressing DoD current needs and valid with 97.4% agreement among the panel for JCA assignment. Application of the rating panel JCA assignments to the SBIR data set shall provide a comparison of commercialization rates by JCA grouping to determine any unique or interesting behavior.

4.5.1 JCA Application and Exclusions

The JCA assignment exercise resulted in 225 SBIR topics assigned to 48 different JCAs that consisted of both second and third tier JCAs. The assigned JCAs were applied to SBIR Phase II contracts by cross-referencing the SBIR topic number. The resulting data set consisted of 214 closed Phase II SBIR contracts that were assigned a JCA. Dummy variables were created for each of the 48 assigned JCA categories. The population of Phase II contracts assigned to each JCA category varied, with a maximum of 29 contracts and a minimum of just one. The JCA assignment logic and justification used by the research team during the JCA assignment process is shown in Appendix J.

In order to avoid Simpson's Paradox, 28 JCA categorical groups and 36 associated contracts were excluded from analysis. Bootstrapping to a SBIR contract population of three contracts was performed on 14 JCA categorical groups with simulation iterations sampling from 160 associated SBIR contracts. The resulting data set consisted of 20 JCA categorical groups and 178 associated SBIR contracts that are fit for commercialization analysis; a visual depiction of the "analysis space" of these programs is shown in Figure 15. The comparison of total population commercialization rates to the standardization sample rate for each bootstrapped JCA categorical group can be found in Table 7.

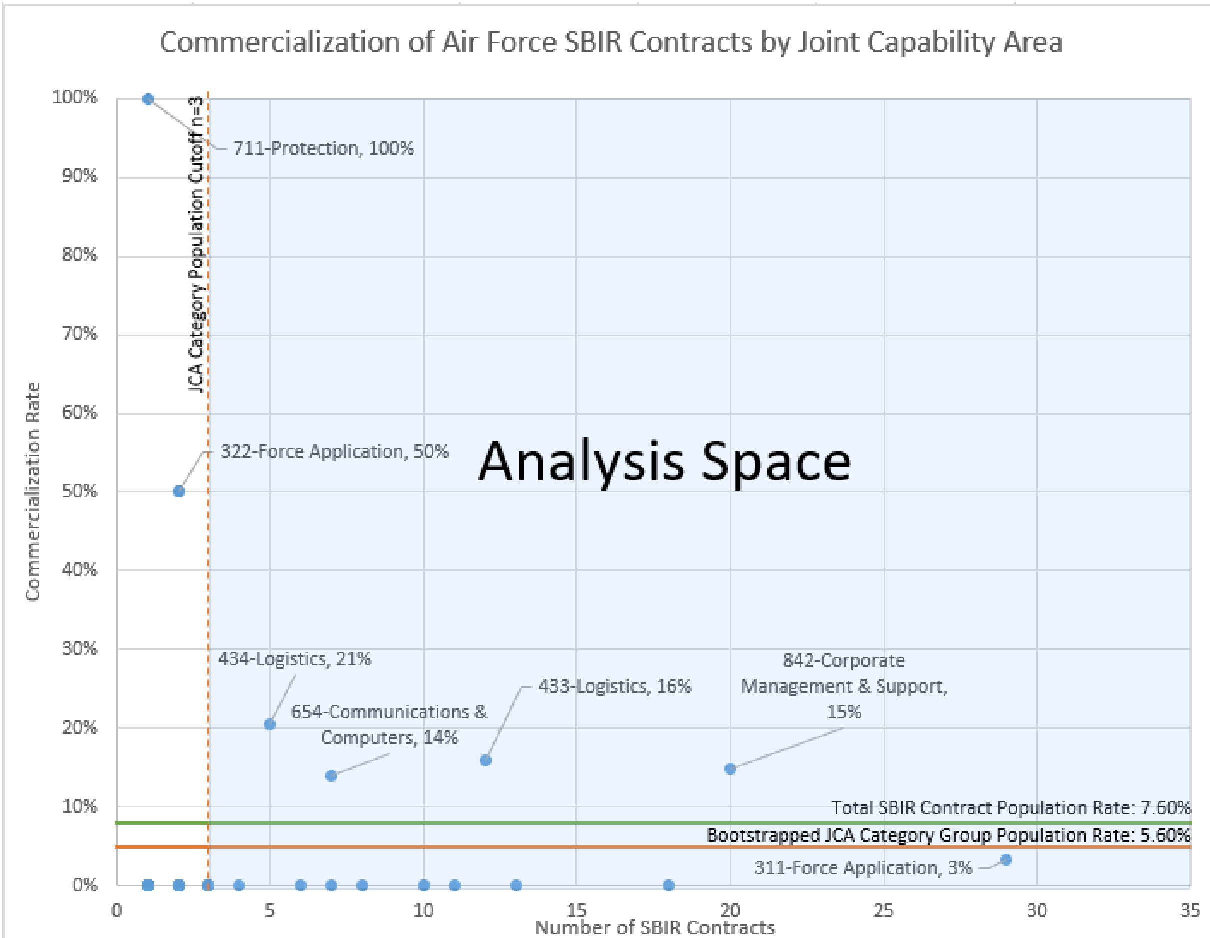

Figure 14. Commercialization of SBIR Contracts by Joint Capability Areas

Table 7. Comparison of JCA Category Rates (Total versus Bootstrapped)

JCA	Contract Population	Commercialized Contracts	Commercialization Rate	Bootstrapped Rate
4.3.4.	5	1	20.0%	20.6%
4.3.3.	12	2	16.7%	16.0%
8.4.2.	20	3	15.0%	14.8%
6.5.4.	7	1	14.3%	14.0%
3.1.1.	29	1	3.4%	3.2%
2.2.2.	6	0	0%	0%
2.3.1.	10	0	0%	0%
2.3.2.	8	0	0%	0%
2.4.	3	0	0%	0%
3.1.2.	18	0	0%	0%
3.2.1.	4	0	0%	0%
4.2.2.	3	0	0%	0%
4.3.1.	10	0	0%	0%
4.3.2.	7	0	0%	0%
5.2.2.	3	0	0%	0%
6.1.2.	11	0	0%	0%
7.1.3.	3	0	0%	0%
7.2.9.	3	0	0%	0%
8.1.5.	3	0	0%	0%
8.4.3.	13	0	0%	0%

4.5.2 Analysis Results

The JCA categories were analyzed for commercialization performance using bootstrapped commercialization rates as noted in Table 7. Several JCA categories outperformed both the total SBIR contract population commercialization rate (7.6%) and the bootstrapped population commercialization rate (5.6%) as shown in Figure 14. These high-performing categories consisted of maintenance repair functions (e.g., squadron-level), maintenance service functions (e.g., depot-level), advanced technology (e.g., state-of-the-art and prototyping), and positioning, navigation & timing (e.g., Global Positioning System). An exhaustive summary of each JCA categories bootstrapped commercialization performance can be found in Figure 16.

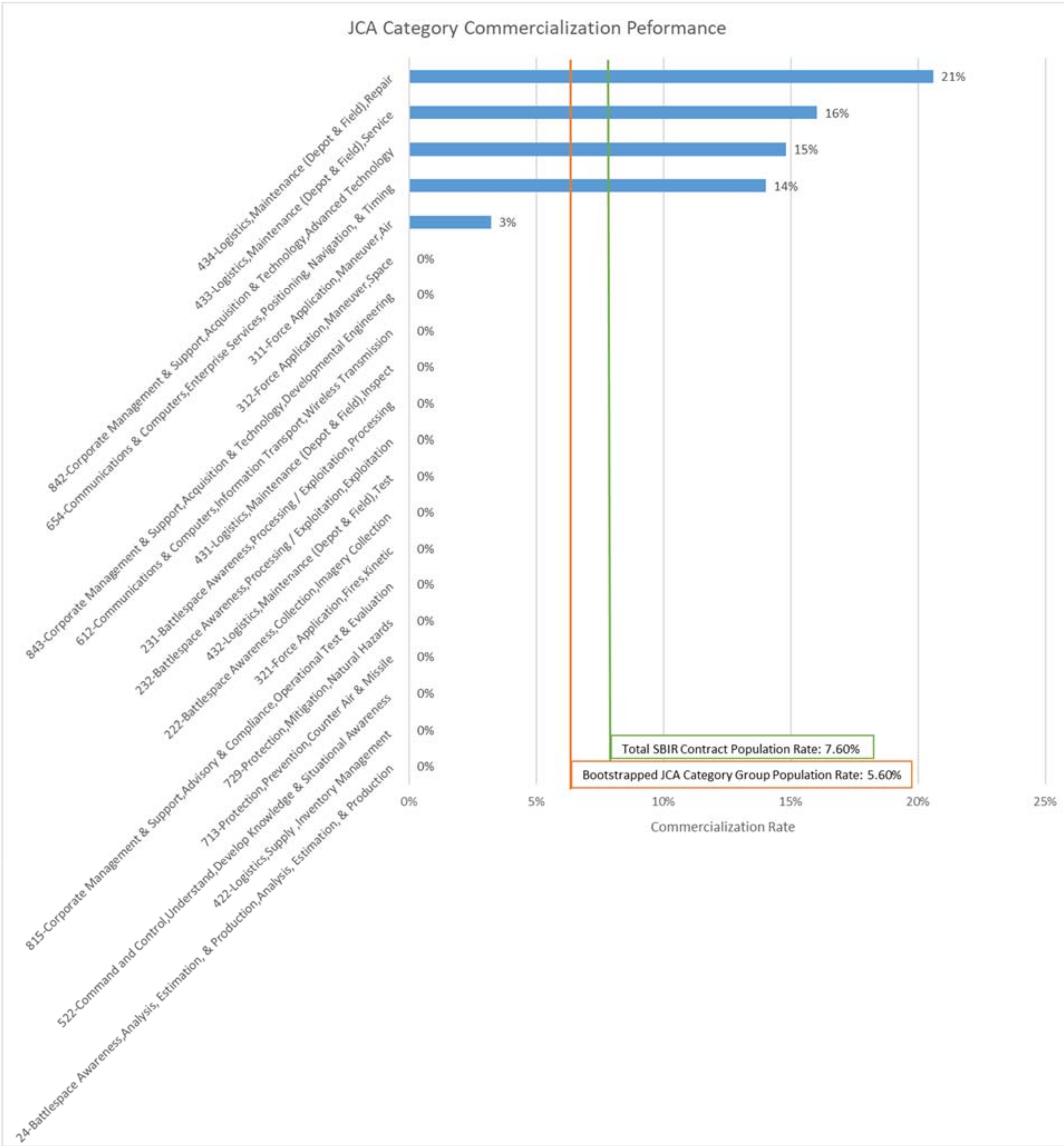

Figure 15. JCA Category Commercialization Performance

4.5.3 Implications

The results of this analysis effort imply that the Air Force SBIR program excels at commercializing areas where we control the technical baseline. Controlling the technical baseline was defined by Barker (2019) as having the “necessary technical resources with the right competencies (skills)” in a technical area and “possessing the technical expertise necessary to engage effectively with industry experts”. The aging fleet of the Air Force requires constant use of maintenance and depot functions as reflected in the high commercialization rate of JCAs involving those efforts. Air Force agencies such as the Air Force Research Lab require proof-of-concept prototypes and advanced technological research to break technical barriers. Positioning, navigation, and timing systems are of DoD-level interest, and the Air Force manages the Global Positioning System through both satellite launch and control.

The majority of low performers reside in technical areas where the Air Force does not control the technical baseline. Categories such as aircraft and space were technical areas once dominated by the Air Force, but they have since become subject to commercial markets who can expand and advance the technical baseline at or beyond the level of the Air Force. Areas such as counter air and battery are DoD specific, but fall in the realm of a sister service, the U.S. Army.

The Air Force either needs to focus SBIR investments into areas where it maintains dominance in the technical baseline or make investments on advancing the baseline in areas in which it does not. The focus of SBIR investments can be traced to the development and solicitation of SBIR topics; sponsoring and managing organizations need to keep the technical baseline in mind when soliciting a topic. Figure 17 depicts the number of SBIR contracts assigned to each first and second tier JCA; minimal investments were made into Force Integration, Command and Control, and Protection JCAs. SBIR topic development with a panel of sponsors, managers, and users, with JCA assignment in mind for each topic, will allow better operational allocation and focused investment within the technical baseline.

Air Force SBIR Investment "Shots on Goal" Per JCA

Joint Capability Area - Tier 2 \ Joint Capability Area - Tier 1	Force Integration (1)	Battlespace Awareness (2)	Force Application (3)	Logistics (4)	Command and Control (5)	Communication and Computers (6)	Protection (7)	Corporate Management (8)
1	1	0	48	0	0	11	4	3
2	1	7	6	6	4	2	9	0
3	0	18		38	1	3	0	0
4		6		0	1	1		33
5		0		0	0	8		0
6		0		2	0			
7				0				
8				0				

Figure 16. Air Force SBIR Investment "Shots on Goal" (Number of SBIR Contracts) per JCA

The snapshot provided in Figure 17 also provides utility beyond identifying SBIR investment, it can be used to identify technical baseline control. Evaluating technical baseline competence to the second tier will allow the Air Force to identify areas for future improvement. Investments in advancing the technical baseline will prove the most difficult, requiring changes to DoD and legislative policies.

Several SBIR topic solicitations were written at a highly technical level; this "sticky" information made comprehending the true nature of the topic difficult during the JCA assignment process. If a research team of Air Force acquisition personnel, several with over 20 years of experience, had difficulty comprehending an Air Force SBIR topic, it could be expected that a prospective SBIR firm would have the same issue. Generalization of technically advanced material is fundamental in drafting DoD acquisition documents; SBIR topic development should be no different. The SBIR program office should identify and correct SBIR topics that fail to meet a general knowledge comprehension requirement.

Exceeding the problem space was an issue encountered during the JCA assignment process for several SBIR topics. These SBIR topics requested weapon systems, components, or technologies that touched multiple JCAs, some to the level of effort for a major defense acquisition program. During SBIR topic development, it is essential for the sponsoring and managing organization to keep the scope of a SBIR effort in mind. If a SBIR topic requires a level of effort beyond $1.93 million, that topic should be decomposed into smaller efforts with the sponsor as the lead integrator or made into a full-fledged acquisition program of record.

The JCA assignment process identified several JCA taxonomy areas of improvement. The current JCAs fail to address sustainment functions of legacy aircraft; these functions would include corrosion protection and component replacement and modernization efforts. Industrial hygiene, and more specifically Occupational Safety and Health Administration compliance efforts, lacked adequate coverage. The current needs perspective of the JCAs failed to cover state-of-the-art capabilities that have recently become prevalent within the DoD, such as artificial intelligence, additive manufacturing, autonomy, and data storage. The JCA taxonomy will need to be updated alongside SBIR topic development to make useful and relevant investments in the SBIR program.

4.6 Summary

The Air Force SBIR program was analyzed for commercialization performance from Fiscal Year 2015 to July 2018. A data set was created from combining Phase II and Company Commercialization Report data sets. Existing categorical data proved insignificant in determining commercialization performance. The DoD Joint Capability Areas were identified as the most adequate taxonomy for categorical analysis through assignment to SBIR topics by a panel of raters.

Air Force ownership of the technical baseline was identified as a discriminating factor in commercialization performance. Improvements to SBIR topic development, the JCA taxonomy, and Air Force ownership of the technical baseline was recommended.

V. Conclusions and Recommendations

5.1 Chapter Overview

This research was motivated by our National Defense Strategy's call for improved innovation. The focus of this research is the performance of our existing SBIR program; at its core, the program seeks to stimulate innovation within the national industrial base. This research accomplished a three-phase analysis of SBIR performance to determine the performance baseline of the existing program. The primary contribution of this research is a capability-based means to categorize and thus measure SBIR investments. Management tools are presented to solidify the utility of this contribution and to derive recommendations for improvement. Future research is suggested to enhance and apply this categorical framework to other areas of interest within the Air Force SBIR Program.

5.2 Conclusions of Research

The research analysis found that the total population of closed phase II SBIR contract efforts had a commercialization rate of 7.6%. Existing categorical data were determined to be insignificant in determining commercialization performance. The DoD JCA taxonomy was identified as a relevant taxonomy for categorical analysis. A panel-of-raters JCA assignment exercise was performed on 225 SBIR topics. Due to variation among populations for each JCA category, standardization was performed on category populations that exceeded three contracts and exclusions performed on category populations that failed to meet three SBIR contracts. The resulting commercialization rate of the 178 bootstrapped SBIR contracts was 5.6% spread across 20 JCA categories as shown in Figure 18. JCAs identified as high-performers consisted of maintenance repair functions (e.g., squadron-level), maintenance service functions (e.g., depot-level), advanced technology (e.g., state-of-the-art and prototyping), and positioning, navigation & timing (e.g., Global Positioning System).

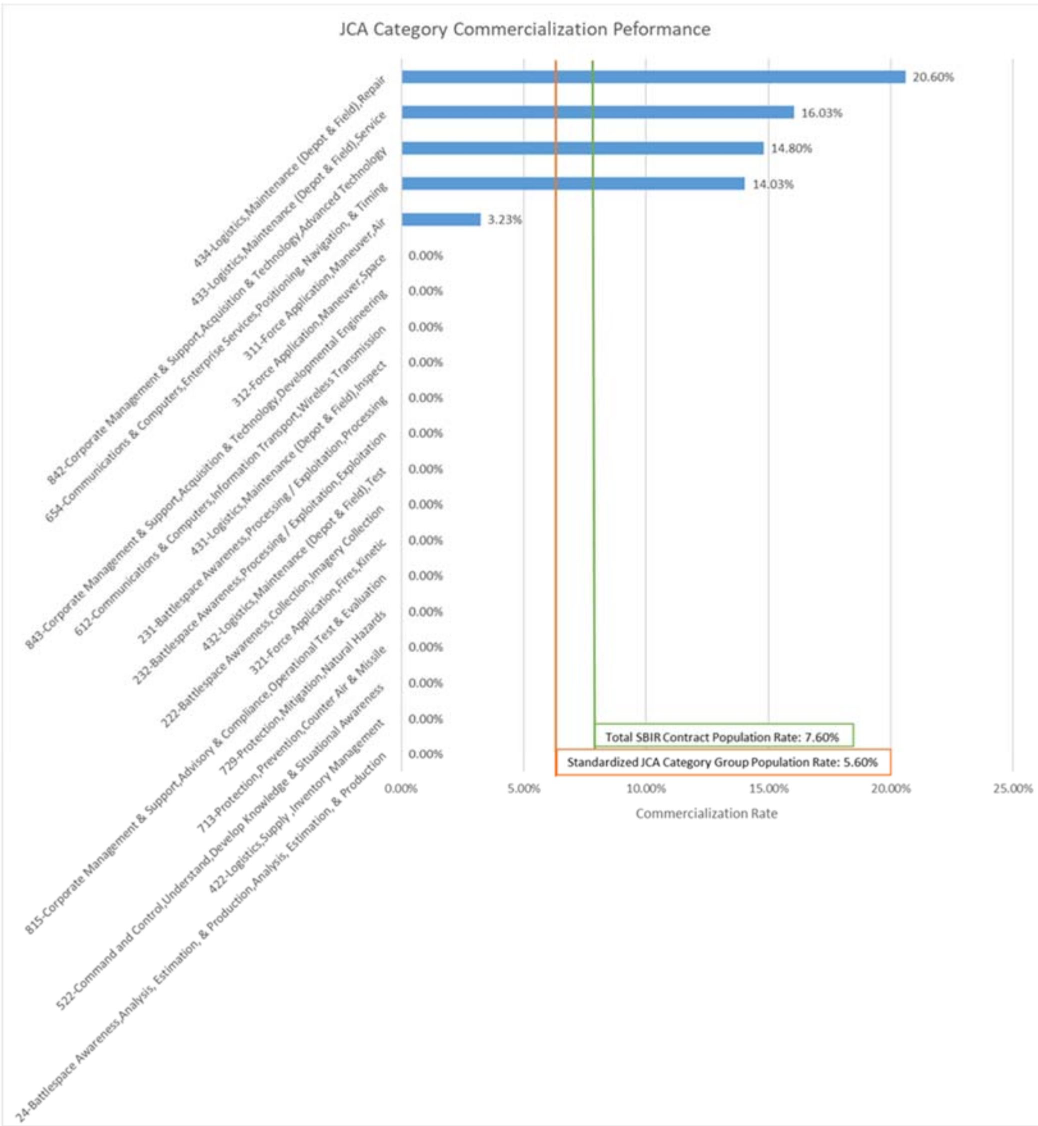

Figure 17. JCA Category Commercialization Performance

The results of this analysis effort imply that the Air Force SBIR program is proficient at commercializing areas where we control the technical baseline. Ownership of the baseline was shared by high-performing JCA categories, while low-performing JCA categories did not. Several

SBIR topic solicitations were written at a highly technical level; this level of technicality impedes a general understanding of the SBIR topic. Some SBIR topics exceeded beyond the level of a SBIR effort towards a program of record or major defense program. The current JCAs address the current needs of the DoD; these capabilities fail to address current needs of sustainment functions and industrial hygiene as well as future needs that are establishing themselves today such as artificial intelligence and data storage.

5.3 Significance of Research

This research effort conducted an extensive commercialization analysis of 178 SBIR contracts that represent over $182 million in SBIR funding. The results of this analysis provide decision makers with a snapshot of "Where am I making my investments?", "How much am I investing?" and "How well are those investments performing?" as shown in Figures 18, 19, and 20. The implications of this analysis identify areas for process and policy improvements to better identify and capitalize on commercializing innovative technologies. The direct effect of this improvement can be realized on an Air Force SBIR program that represents almost $1 billion in annual SBIR funding.

5.3.1 Applicability

The findings of this research effort are not only applicable to Air Force SBIR programs but could have applicability to the overall DoD SBIR program. Technical baseline ownership within DoD acquisition touches every department component such as the Army or Navy. The JCA taxonomy is a DoD joint venture; improvements to the taxonomy will reap benefits across the department. The possibility of cost savings by minimizing duplication of effort with NASA provides benefits to SBIR programs outside of the DoD.

Air Force SBIR Investment "Shots on Goal" Per JCA									
Joint Capability Area - Tier 1		Force Integration	Battlespace Awareness	Force Application	Logistics	Command and Control	Communication and Computers	Protection	Corporate Management
		1	2	3	4	5	6	7	8
Joint Capability Area - Tier 2	1	1	0	48	0	0	11	4	3
	2	1	7	6	6	4	2	9	0
	3	0	18		38	1	3	0	0
	4		6		0	1	1		33
	5		0		0	0	8		0
	6		0		2	0			
	7				0				
	8				0				

Figure 18. Air Force SBIR Investment "Shots on Goal" (Number of SBIR Contracts) per JCA

Air Force SBIR Investment "Funds on Goal" Per JCA									
Joint Capability Area - Tier 1		Force Integration	Battlespace Awareness	Force Application	Logistics	Command and Control	Communication and Computers	Protection	Corporate Management
		1	2	3	4	5	6	7	8
Joint Capability Area - Tier 2	1	$ 1,488,271	$ -	$40,126,582	$ -	$ -	$ 8,357,109	$ 5,960,084	$ 2,992,924
	2	$ 749,074	$ 5,498,301	$ 5,046,156	$ 3,734,972	$ 2,897,974	$ 2,198,340	$ 8,499,432	$ -
	3	$ -	$15,698,365		$31,384,157	$ 1,499,273	$ 2,234,943	$ -	$ -
	4		$ 6,740,212		$ -	$ 749,744	$ 749,095		$27,949,053
	5		$ -		$ -	$ -	$ 5,586,538		$ -
	6		$ -		$ 2,248,818	$ -			
	7				$ -				
	8				$ -				

Figure 19. Air Force SBIR Investment "Funds on Goal" (Value of SBIR Contracts) per JCA

Air Force SBIR Investment "Commercialization on Goal" Per JCA

Joint Capability Area - Tier 2 \ Joint Capability Area - Tier 1	1 Force Integration	2 Battlespace Awareness	3 Force Application	4 Logistics	5 Command and Control	6 Communication and Computers	7 Protection	8 Corporate Management
1	0%		3%			0%	100%	0%
2	0%	0%	50%	0%	0%	0%	0%	
3		0%		29%	0%	0%		
4		0%			0%	0%		15%
5						14%		
6				0%				
7								
8								

Figure 20. Air Force SBIR Investment "Commercialization on Shot" per JCA

5.3.2 Limitations

Several limitations were noted during the research effort:

- The SBIR program data set consists of only Air Force SBIR programs from Air Force Fiscal Year 2015 to July 2018.
- SBIR programs within the data set that failed to include adequate cost or date data to determine Phase II contract closeout were excluded from analysis.
- Open SBIR Phase II contracts were excluded from analysis.
- Monetary commercialization dollars were the only examined success factor; the intrinsic value of diffused technology from SBIR efforts in the DoD or AF was not analyzed.
- Categorical analysis of commercialization performance was only performed on 178 SBIR contracts that were assigned a JCA category and fell within JCA categories that met population requirements of three or more SBIR contracts.

5.4 Investigative Questions (IQs) Answered

The onset of this effort imposed several investigative questions towards the Air Force SBIR program. The successful conclusion of this research effort is obtained by comprehensively addressing each question. Extensive literature review and comprehensive analysis of Air Force SBIR contracts was conducted to provide insight that will answer those questions. The answers to these questions consist of summarized information or findings stated in this chapter or previous chapters.

5.4.1 IQ 1: What is the commercialization performance of Air Force SBIR Programs?

The total commercialization rate of closed Air Force SBIR contracts within the Air Force SBIR program from Fiscal Year 2015 to FY 2018 was 7.60%. An analysis of the JCA categorical assignment resulted in a bootstrapped commercialization rate of 5.60% across 178 closed SBIR contracts.

5.4.2 IQ 2: What are the unique behaviors or patterns demonstrated within that commercialization performance?

Several high performing and low performing technical areas were found with respect to commercialization. High-performing technical areas included maintenance, navigation, and advanced technology. Low-performing technical areas included space launch and developmental engineering.

Several factors may have caused this demonstrated lack of commercialization performance. A market need for the developed technology may not exist. The established need for the technology, conveyed through a SBIR Topic solicitation, may have been unclear due to overly complicated solicitations or requests that extend outside the scope of a SBIR effort. The maturity reverting nature of an immature SBIR component technology on an existing mature legacy weapon system is another concern. Finally, these SBIR efforts may exist within the realm of technical baseline ownership where the Air Force fails to match commercial industry. In such an event, attempts to support and subsequently diffuse the technology within the Air Force can prove unsuccessful.

5.4.3 IQ 3: What methods can be developed to investigate and explain those behaviors and patterns?

The DoD JCA taxonomy provides the best appropriate categorical method to identify and compare commercialization rates among capability areas. This taxonomy of currently needed capabilities provides an operational alignment to SBIR topics. The ability to align SBIR topics to the first, second, and third JCA tier allows various levels of analysis. Assignment by a panel of raters was the best method to assign JCAs to a SBIR topic, resulting in over 97.4% agreement across the SBIR topics assigned. The results of this analysis and future utilization of JCA assignment provides a management tool to identify capability investments, determine how well they perform, and make decisions on where to invest next.

5.4.4 IQ 4: What specific SBIR technologies of interest identified by those methods?

The assignment of JCAs to SBIR contracts provides a capability-driven outlook, rather than a technology-focused outlook. The JCAs that represent areas of interest for SBIR commercialization performance were areas of maintenance, navigation, and advanced technology. Technologies that were not covered by the JCAs but were however identified through SBIR topic review were artificial intelligence, sustainment, industrial hygiene, autonomy, and data storage.

5.5 Recommendations for Action

The recommendations derived from this research effort include refining the SBIR topic development process, updating the JCA taxonomy, and expanding Air Force ownership of technical baselines. Several issues were identified concerning SBIR topic solicitations. Sponsoring organizations appear to have the most input in topic development, which often resulted in SBIR topics with no operational alignment, extensive technical write-ups, and levels of effort beyond the scope of the SBIR program. JCA assignment is a team effort that begins at SBIR topic solicitation. The SBIR program should stress the inclusion of sponsoring, managing, and using organizations within the solicitation process. The effectiveness of the assignment is increased exponentially within the panel system. The SBIR topic solicitation itself should be evaluated for "stickiness" and scope of effort by the same panel.

The current JCA taxonomy fails to account for several current capabilities and advanced capabilities that have recently become prevalent across the DoD. The research effort identified several current and new capabilities that deserve allocation beyond the necessary maintenance, general engineering, and advanced technology categories within the JCAs. The JCA taxonomy should be updated to account for current capabilities such as sustainment and industrial hygiene and new capabilities such as artificial intelligence, autonomy, hypersonics, and data storage.

Further advancement of an Air Force-specific SBIR taxonomy should be created beyond the current JCA taxonomy. An aerospace SBIR community of interest should be established that will oversee a common SBIR taxonomy. This community can consist of the DoD SBIR program, other SBIR agencies such as NASA, sponsor organizations, manager organizations, users, major defense contractors, and high-tech firms such as Google and Apple. The inclusion of this community will result in a SBIR taxonomy that accounts for current, future, and shared needs.

Additionally, the Air Force needs to build upon and enhance its ownership of the technical baseline across all related JCAs of interest. The decision regarding in which joint capabilities to make a knowledge investment should be made by senior leadership. The act of enhancing and expanding ownership can be facilitated through extensive interactions across the previously suggested aerospace SBIR community of interest.

5.6 Recommendations for Future Research

Future research recommendations include expanding analysis on the current data set and conducting additional analysis on related data. Expanding beyond the 225 assigned JCA topics to all 537 SBIR topics within the data set will provide a better snapshot of commercialization performance per category. Coding of the JCAs can follow the implementation logic established in Appendix J. Before performing this analysis, the data set should be updated to account for new contract data developed since the conclusion of this research effort.

A case study analysis of SBIR Phase II programs for commercialization success and failure mechanisms provides an in-depth root cause analysis. Interviews with SBIR firms, sponsors, managers, and the SBIR program office provides a much more extensive set of mechanisms that could be identified through the analysis conducted in this effort. Choosing a category or technology area of interest is recommended, such as unmanned aerial vehicles, space, or hypersonics. Selection criteria of recent (in the past three fiscal years) SBIR contracts are also recommended due to requiring the memory and recollection of individuals.

The Government Accountability Office identified that the self-reporting nature of CCR data by participating SBIR firms as a concern (U.S. Government Accountability Office, 2013; U.S. Government Accountability Office, 2014). Conducting an investigative analysis of Company Commercialization Report (CCR) data to verify commercialization data of a specific SBIR program portfolio will answer accuracy and reliability issues outlined by the GAO. Focusing on a specific SBIR portfolio in similar timeline and category as outlined in the previous recommendation will allow ample data and a sufficient scope to conduct analysis.

Development of an improved Air Force SBIR Program taxonomy that accounts for current JCAs capabilities, future capabilities, and cost-saving possibilities provides future-proof operational alignment to the Air Force SBIR program. The current JCA data set requires some minor tweaking to account for current needs that have "slipped through the cracks," these needs include efforts such as sustainment and industrial hygiene. The addition of future capabilities to the JCAs is a must in a taxonomy that addresses the advanced technologies contained within the Air

Force SBIR program. The NASA SBIR taxonomy contains several shared capabilities with the DoD JCAs; further investigation and coordination between the DoD and NASA could result in unique cost-sharing opportunities.

5.7 Summary

The Air Force SBIR Program has seen a high rate of failure, over 92%, in Phase II efforts that have completed funding within the last three Fiscal Years. An application of DoD mission-centric JCAs to each SBIR effort provides an explicit operational mapping of DoD needs to Air Force SBIR Program efforts. The JCA assignment process and subsequent analysis identified several high performing groups and low performing groups. High performers such as maintenance, advanced technology, and positioning, navigation & timing resided in areas were the Air Force owns the technical baseline. Low performers such as developmental engineering, test, and counter-air and battery reside within baselines that the Air Force does not control. These JCA groupings provide the Air Force SBIR Program focus areas to concentrate funding or attention, to improve the commercialization, or return on investment, of a program that represents almost 1 billion dollars in DoD funding annually.

Appendix A. Joint Capability Area Definitions

JOINT CAPABILITY AREA DEFINITIONS

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Retrieved from the JCA repository site (Department of Defense Joint Staff J8, 2018)

Current as of June 7, 2018

1. **Force Integration** – The ability to establish, develop, and maintain a mission ready Joint Force and build relationships with foreign and domestic partners.

1.1. **Force Management** – The ability to integrate new and existing human and technical assets from across the Joint Force and its mission partners to provide capabilities in support of global operations.

1.1.1. **Global Force Management** – The ability to align force apportionment, assignment, and allocation of forces to combatant commanders in support of the National Defense Strategy and joint force availability requirements

1.1.2. **Force Configuration** – The ability to translate doctrine, organization, training, materiel, leadership and education, personnel, facilities, and policy (DOTmLPF-P) requirements into programs and structure.

1.1.3. **Global Defense Posture Execution** – The ability to develop a global network of host-nation relationships, activities, and footprint of facilities and forces by refining operational requirements for, implementing, and sustaining posture changes.

1.1.4. **Readiness Reporting** – The ability to evaluate, appraise, and characterize the status of military capabilities (including force structure, modernization, unit readiness, and sustainability), joint readiness, and the supporting infrastructure to perform assigned missions.

1.1.5. **Human Capital Management** – The ability to ensure and support, within the life cycle management of total force human resources, the availability of personnel equipped with skill sets required for mission success.

1.2. **Force Preparation** – The ability to develop, enhance, and adapt the Joint Force, complemented by Allies and Partners for unified action.

1.2.1. **Training** – The ability to instruct and apply exercises for acquiring and retaining skills, knowledge, and abilities required to perform specific tasks.

1.2.2. **Exercising** – The ability to conduct military maneuver or simulate wartime operations involving planning, preparation, and execution that is carried out for the purpose of training and evaluation.

1.2.3. **Education** – The ability to convey general bodies of knowledge and develop habits of mind applicable to a broad spectrum of endeavors to foster breadth of view, diverse perspectives, critical analysis, and abstract reasoning.

1.2.4. **Doctrine** – The ability to provide fundamental principles that guide the employment of military forces in coordinated action toward a common objective and serves to make US policy and strategy effective in the application of military power.

1.2.5. **Lessons Learned** – The ability to identify, collect, analyze, validate, disseminate, and operationalize a lesson that contributes to improved performance or increased capability through documentation of lessons and best practices across DOTmLPF-P.

1.2.6. **Concepts** – The ability to examine challenges and opportunities of the future operational environment and identify potential alternate methods of operating and potential required capabilities.

1.2.7. **Experimentation** – The ability to conduct analytic activities derived from unbiased trials conducted under controlled conditions within a representative environment in order to help solve joint challenges/problems/issues.

1.3. **Building Partnerships** – The ability to conduct activities and engage with foreign and domestic partner leaders, security and other government institutions, nongovernmental organizations, and relevant populations to build defense relationships through formal and informal agreements to achieve shared objectives.

1.3.1. **Engage Partners** – The ability to integrate and synchronize interactions with foreign and domestic governments and institutions to facilitate the development of formal or informal partnerships.

1.3.2. **Manage Partnership Agreements** – The ability to develop, maintain, and disestablish partnerships.

1.3.3. **Conduct Security Cooperation Activities** – The ability to assess, monitor, evaluate, sustain, develop, and leverage the military, security, or other capabilities and capacities of partners.

1.3.4. **Conduct Civil-Military Operations** – The ability to establish and maintain relations between military forces, indigenous populations, and institutions by directly support the attainment of objectives relating to stability within a region or host nation.

2. **Battlespace Awareness (BA)** – The ability to understand dispositions and intentions as well as the characteristics and conditions of the operational environment that bear on national and military decision making by leveraging all sources of information to include Intelligence, Surveillance, Reconnaissance, Meteorological, and Oceanographic.

2.1. **Planning & Direction** – The ability to synchronize and integrate the activities of collection, processing, exploitation, analysis and dissemination resources to satisfy intelligence requirements.

2.1.1. **Define & Prioritize Requirements** – The ability to translate national through tactical objectives and needs into intelligence requirements, information requirements, and specific information requirements.

2.1.2. **Develop Plans & Strategies** – The ability to determine and document in plans the best approach to collect, process, exploit, analyze, and disseminate data, information, and intelligence to address requirements and maintain estimates of likely outcomes.

2.1.3. **Task & Monitor Resources** – The ability to task, track, direct, assess, and adjust intelligence operations and their associated resources to fulfill requirements.

2.2. **Collection** – The ability to gather data to satisfy information needs.

2.2.1. **Signals Collection** – The ability to gather information based on the interception of electromagnetic impulses.

2.2.1.1. **Communications (SC)** – The ability to intercept and derive information from voice and data communications.

2.2.1.2. **Electronic Emissions (SC)** – The ability to intercept and derive information from non-communication transmissions.

2.2.1.3. **Foreign Instrumentation (SC)** – The ability to intercept data from foreign equipment and control systems.

2.2.1.4. **Cyberspace Networks (SC)** – The ability to access and gather data from automated information systems, networks, and databases.

2.2.1.5. **Imagery Collection** – The ability to obtain a visual presentation or likeness of any natural or man-made feature, object, or activity at rest or in motion.

2.2.1.6. **Electro-Optical (IC)** – The ability to obtain a visual presentation of any natural or man-made feature, object, or activity derived from the ultraviolet through far infrared electromagnetic spectrum.

2.2.1.7. **Light Detection & Ranging (IC)** – The ability to obtain a visual presentation produced by recording pulsed laser light reflected from a given object.

2.2.1.8. **Radar (IC)** – The ability to obtain a visual presentation produced by recording radar waves from any natural or man-made feature, object, or activity.

2.2.1.9. **Sonar (IC)** – The ability to measure and characterize surfaces, natural or man-made objects, and layers of the maritime and littoral features.

2.2.1.10. **Physical Environment (IC)** – The ability to sense or acquire meteorological, oceanographic, and space environmental data through measurement, monitoring, and sensor observations.

2.2.2. **Measurement & Signature Collection** – The ability to gather parameters and distinctive characteristics of natural or man-made phenomena, equipment, or objects.

2.2.2.1. **Electro-Optical (MSC)** – The ability to collect information on phenomena that emit, absorb, or reflect electromagnetic energy in the ultraviolet through infrared spectrum.

2.2.2.2. **Radar (MSC)** – The ability to actively or passively collect energy reflected from any natural or man-made feature, object, or activity.

2.2.2.3. **Geophysical (MSC)** – The ability to detect phenomena and gather information transmitted through the geophysical area of the earth, oceans, and surrounding atmosphere, including man-made objects.

2.2.2.4. **Radio-Frequency (MSC)** – The ability to collect information from radiation transmissions and electromagnetic pulses.

2.2.2.5. **Materials (MSC)** – The ability to gather information from chemical and biological agents, objects, and activities.

2.2.2.6. **Nuclear Radiation (MSC)** – The ability to obtain information derived from nuclear radiation and other physical phenomena associated with nuclear weapons, reactors, devices, facilities, and fissile materials.

2.2.2.7. **Sonar (MSC)** – The ability to measure and characterize surfaces, natural or man-made objects, and layers of the maritime and littoral environment.

2.2.2.8. **Physical Environment (MSC)** – The ability to sense or acquire meteorological, oceanographic, and space environmental data through measurement, monitoring, and sensor observations.

2.2.2.9. **Biometrics Data (MSC)** – The ability to gather measurable anatomical, physiological, and behavioral characteristics of an individual.

2.2.3. **Human-based Collection (HBC)** – The ability to acquire information from human resources, human-derived data, or human reconnaissance and surveillance assets.

2.2.3.1. **Human Intelligence (HBC)** – The ability to gather information for intelligence purposes from human sources.

2.2.3.2. **Counterintelligence Collection** – The ability to gather information to identify threats posed by foreign governments and organizations, foreign persons, or international terrorists.

2.2.3.3. **Observation** – The ability to use human resources to obtain, by visual observation and other detection methods, information about the physical environment and surrounding activities.

2.2.3.4. **Documents, Media, & Materiel** – The ability to obtain through battlefield seizure or other means, documents electronic media, and foreign materiel.

2.2.3.5. **Social-Cultural Data** – The ability of human resources applying their knowledge of a language, culture, or region to obtain social or cultural information about the operational environment from the individual to the national level.

2.2.4. **Open Source Collection** – The ability to acquire information from publicly available documents and electronic media.

2.3. **Processing & Exploitation** – The ability to convert collected information into forms suitable for further analysis and/or action.

2.3.1. **Processing** – The ability to convert raw data into forms suitable for exploitation.

2.3.1.1. **Signals Data Processing** – The ability to convert raw data from electromagnetic impulses into forms suitable for exploitation.

2.3.1.2. **Imagery Data Processing** – The ability to convert raw data representing natural or man-made features, objects, or activities at rest or in motion into forms suitable for exploitation.

2.3.1.3. **Measurement & Signature Data Processing** – The ability to convert raw data associated with parameters and distinctive characteristics of natural or man-made phenomena, equipment, or objects into forms suitable for exploitation.

2.3.1.4. **Human-acquired Data, Media, & Materiel Processing** – The ability to convert raw data, documents, electronic media, or foreign materiel gathered from or seized by human sources into forms suitable for exploitation.

2.3.1.5. **Open-sourced Data Processing** – The ability to convert raw data obtained from publicly available documents and electronic media into forms suitable for exploitation.

2.3.2. **Exploitation** – The ability to transform processed data into information for immediate use or for additional analysis in the production of intelligence.

2.3.2.1. **Signals Data Exploitation** – The ability to select and transform raw signals data into intelligible information for immediate use or further analysis.

2.3.2.2. **Imagery Data Exploitation** – The ability to select and transform processed imagery data into intelligible information for immediate use or further analysis.

2.3.2.3. **Measurement & Signature Data Exploitation** – The ability to select and transform processed measurement and signature data into intelligible information for immediate use or further analysis.

2.3.2.4. **Human-acquired Data, Media, & Materiel Exploitation** – The ability to select and transform raw data, media, or materiel gathered from or seized by human sources into intelligible information for immediate use or further analysis.

2.3.2.5. **Open-Sourced Data Exploitation** – The ability to select and transform data gathered from publicly available sources into intelligible information for immediate use or analysis.

2.3.3. **Report Generation** – The ability to document the results of processing and exploitation in text, graphic, or other forms for subsequent dissemination to intelligence analysts or other consumers.

2.3.3.1. **Signals Intelligence Report Generation** – The ability document the results of signals data exploitation in text, graphic, or other forms.

2.3.3.2. **Imagery Intelligence Report Generation** – The ability to document the results of imagery data exploitation in text, graphic, or other forms.

2.3.3.3. **Geospatial Intelligence Report Generation** – The ability to document the results of geographically-referenced imagery intelligence in text, graphic, or other forms.

2.3.3.4. **Measurement & Signature Intelligence Report Generation** – The ability to document the results of measurement and signature data exploitation in text, graphic, or other forms.

2.3.3.5. **Counterintelligence Report Generation** – The ability to document the exploitation of information regarding threats posed by foreign governments and organizations, foreign persons, or international terrorists in text, graphic, or other forms.

2.3.3.6. **Human Intelligence Report Generation** – The ability to document the exploitation of information gathered from human sources in text, graphic, or other forms.

2.3.3.7. **Documents & Media Report Generation** – The ability to document information derived from the exploitation of seized or publically available documents and electronic media in text, graphic, or other forms.

2.3.3.8. **Technical Intelligence Report Generation** – The ability to document information derived from the exploitation of foreign materiel in text, graphic, or other forms.

2.4. **Analysis, Estimation, & Production** – The ability to integrate, evaluate, analyze, and interpret information from all available sources to develop intelligence that enables situational awareness of the current state of the operational environment (OE) and an understanding of the relative probability of alternative future conditions of the OE and adversary activity.

2.4.1. **Integration** – The ability to identify, assimilate and correlate relevant information from single or multiple sources.

2.4.2. **Evaluation** – The ability to provide focused examination of the information and assess its reliability and credibility to a stated degree of confidence.

2.4.3. **Interpretation** – The ability to derive knowledge and develop new insight from gathered information to postulate its significance.

2.4.4. **Estimation** – The ability to determine the relative order of probability of alternative future conditions of the OE and adversary activity.

2.4.5. **Product Generation** – The ability to document intelligence in text, graphic, and other forms.

2.4.5.1. **Warning Intelligence Product Generation** – The ability to document intelligence assessments relating to time-sensitive threats against US security, interests, or citizens.

2.4.5.2. **Current Intelligence Product Generation** – The ability to document intelligence assessments needed to support on-going military operations through concise, objective assessments of the current situation in a particular area.

2.4.5.3. **General Military Intelligence Product Generation** – The ability to document intelligence assessments on the military capabilities of foreign countries and organizations, to include non- state actors, and other topics that could affect potential US or multinational military operations.

2.4.5.4. **Target Intelligence Product Generation** – The ability to document intelligence assessments that portray, characterize, and locate the components of a target or target complex, networks, and support infrastructure, and to indicate their vulnerability and relative importance to the adversary.

2.4.5.5. **Scientific & Technical Intelligence Product Generation** – The ability to document intelligence assessments on foreign developments in basic and applied sciences and technologies with warfare potential and, in particular, enhancements to foreign weapon systems.

2.4.5.6. **Counterintelligence Product Generation** – The ability to document intelligence assessments on threats to the Department of Defense (DoD) posed by foreign intelligence entities.

2.4.5.7. **Identity Intelligence Production Generation** – The ability to document the fusion of a variety of identity attributes (biological, biographic, behavioral, and reputational information related to individuals) to reveal the existence of previously unknown individual actors who may pose threats to US interests.

2.4.5.8. **Estimative Intelligence Product Generation** – The ability to document intelligence estimates that forecast in relative order of probability the full range of alternative situations and adversary courses of action with implications for planning and executing military operations.

2.5. **BA Dissemination & Integration** – The ability to transmit, distribute, present, or make available collected data, information reports, or intelligence products.

2.5.1. **BA Data Transmission** – The ability to send collected data directly to processing, exploitation analysis, production and visualization systems, leveraging both Department of Defense Information Network (DODIN) and intelligence-controlled systems.

2.5.2. **BA Data Access** – The ability to provide authorized customer access to data and products, leveraging both DODIN and intelligence- controlled systems.

2.6. **Counterintelligence (CI)** – The ability to identify, deceive, exploit, disrupt, or protect against espionage, other intelligence activities, sabotage, or assassinations conducted by or on behalf of foreign powers, organizations, or persons, or by international terrorist organizations or activities.

2.6.1. **Offensive CI** – The ability to develop information on and provide information, materials, or equipment to a Foreign Intelligence Entity (FIE) for the purpose of penetrating the FIE, or exploiting, disrupting, or manipulating the FIE target.

2.6.2. **Investigations** – The ability to determine whether a person is acting on behalf of, or an event is related to, a foreign power engaged in spying or committing espionage, sabotage, treason, sedition, subversion, assassinations, or international terrorist activities, and to determine actions required to neutralize such acts.

3. **Force Application** – The ability to integrate maneuver and kinetic, electromagnetic, and informational fires to gain a position of advantage and/or create lethal or nonlethal effects on designated targets.

3.1. **Maneuver** – The ability to move to a position of advantage.

3.1.1. **Air** – The ability to move to a position of advantage in the air domain.

3.1.2. **Space** – The ability to move to a position of advantage in the space domain.

3.1.3. **Land** – The ability to move to a position of advantage in the land domain.

3.1.4. **Maritime** – The ability to move to a position of advantage in the maritime domain, excluding the air space above the maritime domain.

3.1.5. **Cyberspace** – The ability to move to a position of advantage in the cyberspace domain.

3.1.6. **Electromagnetic Spectrum** – The ability to move to a position of advantage within the electromagnetic spectrum.

3.2. **Fires** – The ability to create lethal and/or nonlethal effects on designated targets.

3.2.1. **Kinetic** – The ability to create lethal or nonlethal effects on designated targets in the air, land, space, and maritime domains.

3.2.2. **Electromagnetic** – The ability to create lethal or nonlethal effects on designated targets with electromagnetic energy.

3.2.3. **Information** – The ability to create effects on humans and automated systems in the information environment.

3.2.3.1. **Inform** – The ability to communicate accurate information to domestic, international, and internal audiences.

3.2.3.2. **Influence** – The ability to affect the factors that drive the behavior of foreign individuals, groups, and populations.

3.2.4. **Cyberspace** – The ability to manipulate or degrade, disrupt, or destroy designated targets in and through cyberspace, external to the DODIN.

4. **Logistics** – The ability to project and sustain the Joint Force.

4.1. **Deployment & Distribution** – The ability to strategically and operationally move forces and sustainment in support of military operations.

4.1.1. **Force Deployment** – The ability to transport units, equipment and initial sustainment from the point of origin to the point of need.

4.1.2. **Force Sustainment** – The ability to deliver supplies, equipment, and personnel replacements to the joint force.

4.2. **Supply** – The ability to identify and select supply sources, schedule deliveries, receive, verify, and transfer product and authorize supplier payments. This includes the ability to see and manage inventory levels, capital assets, domestic business rules, supplier networks and agreements (to include import requirements) as well as assessment of supplier performance.

4.2.1. **Supplies & Equipment Management** – The ability to maintain accountability, store, preserve, and set stockage levels of materiel and equipment.

4.2.2. **Inventory Management** – The ability to receive materiel in the right quality and quantity and to enable precise distribution and transfer of materiel to the customer while integrating and optimizing the links or business processes between supply nodes, maintenance, and distribution providers.

4.2.3. **Global Supplier Networks Management** – The ability to source routine and surge requirements from the U.S. industrial base, ensure global supply availability and the capacity to support operations involving U.S., IA, PVO, and MN partners engaged in ever changing military activities around the globe.

4.3. **Maintenance (Depot & Field)** – The ability to manufacture and retain materiel in a serviceable condition or restore materiel to a serviceable condition.

4.3.1. **Inspect** – The ability to determine faults or verify repairs or determine condition of an item of equipment based on established equipment maintenance and serviceability standards.

4.3.2. **Test** – The ability to evaluate the operational condition of an end item or subsystem thereof against an established standard or performance parameter.

4.3.3. **Service** – The ability to conduct preventive maintenance checks and scheduled maintenance to detect, correct or prevent minor faults before these faults cause serious damage, failure, or injury.

4.3.4. **Repair** – The ability to restore an item to serviceable condition through correction of a specific failure or condition.

4.3.5. **Rebuild** – The ability to recapitalize an item to a standard as nearly as possible to its original condition in appearance, performance, and life expectancy.

4.3.6. **Calibrate** – The ability to compare an instrument with an unverified accuracy to an instrument of known or greater accuracy to detect and correct any discrepancy in the accuracy of the unverified instrument.

4.3.7. **Reclaim** – The ability to retain and/or demilitarize authorized end items, assemblies, and sub-assemblies prior to disposal.

4.4. **Logistics Services** – The ability to provide services and functions essential to the technical management and support of the joint force.

4.4.1. **Food Services** – The ability to plan, synchronize and manage subsistence support to the joint force to include dining facility management, subsistence procurement and storage, food preparation, field feeding and nutrition awareness.

4.4.2. **Water & Ice Services** – The ability to produce, test, store and distribute bulk, packaged and frozen water in a contingency environment.

4.4.3. **Contingency Base Services** – The ability to provide shelter, billeting, waste management and common user life support management in a contingency environment.

4.4.4. **Hygiene Services** – The ability to provide laundry, shower, textile and fabric repair support.

4.4.5. **Mortuary Affairs** – The ability to conduct contingency fatality operations, and conduct mortuary operations for the remains of persons and personal effects for whom DoD Components are responsible by policy and statute.

4.5. **Operational Contract Support** – The ability to plan for and obtain supplies, services, and construction from commercial sources in support of joint operations along with the associated contract support, integration, contracting support, and management functions.

4.5.1. **Contract Support Integration** – The ability to provide coordinated and synchronized contracted support being executed in a designated operational area in support of the Joint Force.

4.5.2. **Contractor Management** – The ability to oversee and integrate contractor personnel and associated equipment providing support to the Joint Force in a designated operational area.

4.6. **Engineering** – The ability to execute and integrate combat, general, and geospatial engineering to meet national and JFC requirements to assure mobility, provide infrastructure to position, project, protect, and sustain the joint force, and enhance visualization of the operational area, across the full spectrum of military operations.

4.6.1. **General Engineering** – The ability to employ engineering capabilities and activities, other than combat engineering, that provide infrastructure and modify, maintain, or protect the physical environment. Examples include: the construction, repair, maintenance, and operation of infrastructure, facilities, lines of communication and bases; terrain modification and repair; and selected explosive hazard activities.

4.6.1.1. **Gap Crossing** – The ability to enable joint forces to overcome breaks or openings in terrain (dry or wet, natural or man-made).

4.6.1.2. **Develop & Maintain Facilities** – The ability to develop, rehabilitate, and maintain facilities and infrastructure by providing design, real estate, construction, and environmental services which extend through final disposition.

4.6.1.3. **Establish Lines of Communication** – the ability to assess, construct, repair, and improve routes, railroads, intermodal facilities, and supporting infrastructure to allow the speedy flow of personnel, supplies, and equipment into theater and forward to tactical units.

4.6.1.4. **Global Access Engineering** – The ability to enable theater access by determining and documenting infrastructure capacities, in- situ soils, hydrology, and environmental conditions, and forecast and mitigate limitations to enable deployment and improve throughput capacities.

4.6.1.5. **Repair & Restore Infrastructure** – The ability to rehabilitate critical infrastructure. This capability includes repairing or demolishing damaged buildings, restoring utilities such as electrical power, and bringing critical facilities such as hospitals, water treatment plants and waste management facilities online.

4.6.1.6. **Harden Key Infrastructure & Facilities** – The ability to apply site- and threat-adaptable plans and designs, advanced construction techniques and materials in order to enhance the prevention or mitigation of hostile actions against materiel resources, facilities and infrastructure.

4.6.1.7. **Master Facility Design** – The ability to integrate land use, bills of material and forecasts, and construction requirements that facilitate project execution and developing infrastructure and facilities.

4.6.2. **Combat Engineering** – The ability to employ engineering capabilities and activities that support the maneuver of land combat forces and that require close support to those forces. Combat engineering consists of three types of capabilities and activities: mobility, counter-mobility, and survivability.

4.6.2.1. **Defeat Explosive Hazards** – The ability to locate and neutralize the full range of enemy and friendly explosive hazards that may impede routine operations, decrease mobility or present a threat to force protection. It includes the capability to locate, avoid, and neutralize hazards in concert with mounted or dismounted maneuver (breach) or as part of tactical/operational movement (route clearance).

4.6.2.2. **Enhance Mobility** – The ability to enable both mounted and dismounted movement and maneuver where and when desired without interruption or delay through complex terrain (ranging from littoral to mountainous areas), built up areas (cities, towns, and villages to include subterranean structures), and complex manmade and natural obstacles to achieve the commander's intent without loss of speed or flexibility.

4.6.2.3. **Deny Movement & Maneuver** – The ability to enable the Joint Force Commander to quickly dominate terrain and modify the physical environment in order to isolate forces, deny key terrain and impede, deny or canalize movement via lethal and nonlethal means.

4.6.2.4. **Enhance Survivability** – The ability to provide coordinated and synchronized engineer support (including camouflage techniques) and construction to increase force protection and conserve the Joint Force's fighting capabilities and freedom of action.

4.6.3. **Geospatial Engineering** – The ability to portray and refine data pertaining to the geographic location and characteristics of natural or constructed features and boundaries in order to provide engineer services. Examples include: terrain analyses, terrain visualization, digitized terrain products, nonstandard tailored map products, facility support, and force bed-down analysis.

4.6.3.1. **Utilize Geospatial Data** – The ability to provide the Joint Force Commander with the foundation layer of the operational environment for use with collaborative decision-support, and terrain analysis tools.

4.6.3.2. **Provide Mobility Assessments** – The ability to understand a planned area of operations through the development of assessments on aerial and sea ports, transportation networks, cross country mobility, and mobility corridors.

4.7. **Base & Installation Support** – The ability to provide enduring bases and installations with the assets, programs, and services necessary to support US military forces.

4.7.1. **Real Property Life Cycle Management** – The ability to acquire, operate, sustain, recapitalize, realign, and dispose of real property assets to meet the requirements of the force.

4.7.2. **Installation Services** – The ability to deliver selected services not related to real property or personnel services to meet the requirements of the installation population and mission, to include emergency services, installation safety, base support vehicles and equipment, housing services, airfield management, port services, range management, launch support services, and installation feeding.

4.8. **Health Services** – The ability to perform, provide, or arrange the promotion, improvement, conservation, or restoration of human mental and physical well-being.

4.8.1. **Operational Medicine** – The ability to sustain and protect the health and effectiveness of the Joint Force and provide safe and effective movement of ill and injured personnel to higher levels of care within and outside the Joint Operational Area. This includes the ability to provide for a healthy, fit, and protected force; engage in health surveillance; and manage casualties in a Joint Operational area; and safeguard the health of detained personnel.

4.8.2. **Health Services Delivery** – The ability to provide acute or long- term primary or specialty care to the Joint Force outside of Joint Operational Areas in either the direct or contracted care system and build healthy communities by managing and delivering the health benefit. This ability includes clinical preventive medicine, clinical diagnostics, treatment, rehabilitation, and regeneration.

5. **Command & Control** – The ability to exercise authority and direction by a properly designated commander or decision maker over assigned and attached forces and resources in the accomplishment of the mission.

5.1. **Organize** – The ability to align or synchronize interdependent and disparate entities, including their associated processes and capabilities to achieve unity of effort.

5.1.1. **Establish & Maintain Unity of Effort with Mission Partners** – The ability to foster and maintain cooperative relations with mission partners.

5.1.2. **Structure Organization to Mission** – The ability to dynamically organize elements and define roles, responsibilities, and authorities.

5.1.3. **Foster Organizational Collaboration** – The ability to establish internal structures and processes and external interfaces that facilitate interaction and coordination.

5.2. **Understand** – The ability to individually and collectively comprehend the implications of the character, nature, or subtleties of information about the operational environment and situation.

5.2.1. **Organize Information** – The ability to discover, select, and distill information within an established context.

5.2.2. **Develop Knowledge & Situational Awareness** – The ability to apply context, experience, and intuition to data and information to derive meaning and value.

5.2.3. **Share Knowledge & Situational Awareness** – The ability to communicate synthesized information and context.

5.3. **Plan** – The ability to establish a framework to employ resources to achieve a desired outcome or effect.

5.3.1. **Analyze Problem** – The ability to review and examine all available information to determine necessary actions.

5.3.2. **Apply Situational Understanding** – The ability to use synthesized information and awareness applicable to a given situation or environment to further understand the problem.

5.3.3. **Develop Strategy** – The ability to create a framework that synchronizes and integrates the resources available to achieve a desired outcome or effect.

5.3.4. **Develop Courses of Action** – The ability to determine and refine sequences of activities to achieve a desired outcome or effect.

5.3.5. **Analyze Courses of Action** – The ability to evaluate potential solutions to determine likelihood of success.

5.4. **Decide** – The ability to select a course of action informed and influenced by the understanding of the environment or a given situation.

5.4.1. **Manage Risk** – The ability to recognize and balance the likelihood and consequences of undesired effects with the desired outcomes/effects.

5.4.2. **Select Actions** – The ability to choose a prudent idea or set of ideas that leads to a desired outcome or end-state within a defined set of constraints.

5.4.3. **Establish Rule Sets** – The ability to construct directives that delineate circumstances and limitations for actions.

5.4.4. **Establish Intent & Guidance** – The ability to formulate a concise expression of purpose, methods, acceptable risk, and desired end-state.

5.5. **Direct** – The ability to employ resources to achieve an objective.

5.5.1. **Communicate Intent & Guidance** – The ability to promulgate a concise expression of the operational purpose, assessment of acceptable operational risk, and guidance to achieve the desired end-state.

5.5.2. **Task** – The ability to direct actions and resources.

5.5.3. **Establish Metrics** – The ability to establish objective criteria to assess performance and results.

5.6. **Monitor** – The ability to adequately observe and assess events/effects of a decision.

5.6.1. **Assess Compliance with Guidance** – The ability to determine if performance adheres to established parameters and expectations.

5.6.2. **Assess Effects** – The ability to analyze, track, and measure the results of actions taken.

5.6.3. **Assess Achievement of Objectives** – The ability to determine when the desired end-state has been reached.

5.6.4. **Assess Guidance** – The ability to determine if direction is achieving the desired end-state and is appropriate for the situation.

6. **Communications & Computers** – The ability to share and protect information across DoD and with partners.

6.1. **Information Transport** – The ability to transport information and services via assured end-to-end connectivity.

6.1.1. **Wired Transmission** – The ability to transfer data or information with an electrical/optical conductor.

6.1.2. **Wireless Transmission** – The ability to transfer data or information without an electrical/optical conductor.

6.1.3. **Switching & Routing** – The ability to move data and information end-to-end across multiple transmission media.

6.2. **Network Management** – The ability to configure and re-configure networks, services and the underlying physical assets that provide end-user services, as well as connectivity to enterprise application services.

6.2.1. **Optimized Network Functions & Resources** – The ability to provide DoD with responsive network functionality and dynamically configurable resources, to include allocation of required bandwidth, computing and storage.

6.2.2. **Deployable, Scalable, & Modular Networks** – The ability to design, assemble, transport, and establish mission-scaled networks from adaptable components network modules.

6.2.3. **Spectrum Management** – The ability to synchronize, coordinate, and manage all elements of the electromagnetic spectrum through engineering and administrative tools and procedures.

6.3. **Cybersecurity** – The ability to protect, defend and restore information and information systems, including Platform Information Technology (PIT).

6.3.1. **Information Exchange Security** – The ability to secure dynamic information flow within and across domains.

6.3.2. **Networks Protection** – The ability to anticipate and prevent successful cyberspace threat incidents on networks.

6.3.3. **Data Protection** – The ability to prevent theft, accidental loss, or corruption of data across applications, networks, and databases.

6.3.4. **Identity & Access Management** – The ability to control access to information systems.

6.3.5. **Application Security** – The ability to secure an application by preventing exceptions to the application's security policy or the underlying information system.

6.3.6. **Cyberspace Survivability** – The ability to mitigate effects of malicious cyberspace activity and resulting system degradation by preserving critical functions performance at threshold levels during a cyberspace threat incident, and then after a cyberspace threat incident recover full functionality within a specified mission-relevant timeframe. Systems include, but are not limited to, enterprise and organizational networks, weapons systems, and critical infrastructures.

6.4. **Defensive Cyberspace Operations (Internal Defensive Measures)** – The ability to defeat on-going or imminent threats to defend DoD cyberspace capabilities through systems actions internal to the DODIN.

6.4.1. **Cyberspace Defense** – The ability to provide defense of networks, to include at the boundary.

6.5. **Enterprise Services** – The ability to provide to all authorized users awareness of and access to all DoD information and DoD-wide information services.

6.5.1. **Information Sharing** – The ability to make information visible, accessible, understandable, trusted, and interoperable via secure physical and virtual access to hosted information and data centers across the enterprise and with mission partners based on established data standards.

6.5.2. **Computing Services** – The ability to process data and provide physical and virtual access to hosted information and data centers across the enterprise based on established data standards.

6.5.3. **Common Enterprise Services** – The ability to provide awareness of, access to and delivery of information on the DODIN via a set of registered services.

6.5.4. **Positioning, Navigation, & Timing** – The ability to determine accurate and precise location, orientation, time and course corrections anywhere in the battlespace and to provide timely and assured PNT services across the DoD enterprise.

7. **Protection** – The ability to preserve the effectiveness and survivability of military and nonmilitary personnel, equipment, facilities, and infrastructure by preventing, mitigating, and ensuring recovery from attacks, CBRN incidents, and other hazards.

7.1. **Prevention** – The ability to avoid or neutralize an imminent or on- going attack on personnel and physical assets.

7.1.1. **Concealment/Stealth** – The ability to prevent detection of personnel or physical assets through active and passive measures.

7.1.2. **Countering Weapons of Mass Destruction** – The ability to curtail the conceptualization, development, possession, proliferation, and use of weapons of mass destruction, related expertise, materials, technologies, and means of delivery.

7.1.3. **Counter Air & Missile** – The ability to neutralize imminent and on-going attacks by air and missile threats.

7.1.4. **Physical Security** – The ability to prevent unauthorized accessto personnel, equipment, installations, and information, and to safeguard them against espionage, sabotage, terrorism, damage, and criminal activity.

7.2. **Mitigation** – The ability to minimize the effects and manage the consequence of attacks and designated emergencies on personnel and physical assets.

7.2.1. **Explosive** – The ability to minimize the effects of explosives attacks on personnel and physical assets.

7.2.2. **Projectile** – The ability to minimize the effects of projectile attacks on personnel and physical assets.

7.2.3. **Chemical** – The ability to minimize the effects of chemical attacks and emergencies on personnel and physical assets.

7.2.4. **Biological** – The ability to minimize the effects of biological attacks and emergencies on personnel and physical assets.

7.2.5. **Radiological** – The ability to minimize the effects of radiological attacks and emergencies on personnel and physical assets.

7.2.6. **Nuclear** – The ability to minimize the effects of nuclear attacks on personnel and physical assets.

7.2.7. **Electromagnetic Effects** – The ability to minimize the effects of electromagnetic interference, electromagnetic pulse, and other electromagnetic hazards.

7.2.8. **Directed Energy** – The ability to minimize the effects of directed energy attacks on personnel and physical assets.

7.2.9. **Natural Hazards** – The ability to minimize the effects of natural hazards on personnel and physical assets.

7.3. **Recovery** – The ability to remove remaining hazards from the operational environment.

7.3.1. **CBRN Response** – The ability to neutralize, contain, or minimize the effects of a CBRN incident.

7.3.2. **Maritime Counter-Mine** – The ability to clear a mined area in the maritime domain.

8. **Corporate Management & Support** – The ability to provide strategic senior level, enterprise-wide leadership, direction, coordination, and oversight through a chief management officer function.

8.1. **Advisory & Compliance** – The ability to ensure compliance with statutory, regulatory, and policy requirements and to propose changes to those requirements.

8.1.1. **Legal Advice** – The ability to support decision makers on all civil, acquisition, fiscal, military, international, and operational law issues.

8.1.2. **Legislative Advice** – The ability to advise and assist DoD leaders on all issues involving Congressional testimony or reporting.

8.1.3. **Audit, Inspection, & Investigation** – The ability to understand and monitor matters relating to effective operations of DoD with particular regard to internal review activities.

8.1.4. **Personnel Security Investigations & Clearance Certification** – The ability to assess and certify the reliability and credibility of individuals to hold a particular security clearance.

8.1.5. **Operational Test & Evaluation** – The ability to assess systems for their operational effectiveness, suitability, and survivability in relevant operational environments.

8.2. **Strategic Management** – The ability to establish the direction and priority of activities of the DoD.

8.2.1. **Strategy Development** – The ability to establish DoD direction, strategic goals, priorities, objectives, guidance, and total force capability requirements.

8.2.2. **Capability Development** – The ability to identify, validate, and prioritize capability requirements and associated capability gaps.

8.2.3. **Performance Management** – The ability to direct, supervise, advise, formulate policy, analyze, evaluate, and recommend performance measures/targets that support the DoD mission, strategic goals, objectives, priorities, and policies.

8.2.4. **Enterprise Risk Management** – The ability to identify, analyze, and evaluate risks using a structured and systematic approach to recognize where the potential for undesired outcomes or opportunities can arise, including the ability to develop alternatives, responds to risks, and monitor and review performance.

8.2.5. **Studies & Analyses** – The ability to conduct reviews with appropriate rigor to support decision making for policy development, management, and administration of DoD capabilities, programs and activities.

8.2.6. **Enterprise Architecture** – The ability to develop, implement, and maintain an Enterprise Architecture to guide the development of integrated warfighting and business capabilities within DoD and guide, constrain, and permit implementation of interoperable defense systems and solutions.

8.3. **Information Management** – The ability to establish and oversee policies, standards, and assessment mechanisms for organization, security, access, and storage of data, information, and Information Technology architectures.

8.4. **Acquisition & Technology** – The ability to provide materiel for DoD operations.

8.4.1. **Research** – The ability to conduct fundamental research, science, technology, development and experimentation for all DoD capabilities and operations.

8.4.2. **Advanced Technology** – The ability to produce innovative and unique components and prototypes that can be integrated into defense systems for field experiments and/or tests in a simulated or operational environments to assess military utility.

8.4.3. **Developmental Engineering** – The ability to design and build DoD weapons and other systems, including the ability to conduct developmental testing.

8.4.4. **Acquisition Management** – The ability to manage DoD and Industry activities to acquire materiel for DoD operations. This includes program initiation, contracting, portfolio system acquisition, production and lifecycle acquisition, and capability termination and disposal.

8.5. **Financial Management** – The ability to direct, supervise, provide advice, formulate policy, and conduct analysis on DoD program, budget, performance, and financial matters.

8.5.1. **Programming & Budgeting** – The ability to direct, supervise, advise, formulate policy, analyze, evaluate, and recommend efficient and effective resource allocation and performance targets/metrics that support DoD missions, strategic goals, objectives, priorities, and approved strategies and policies including the ability to direct, formulate, justify, and present the costs, efficiency, effectiveness, and capabilities of DoD programs and Defense budgets timely and accurately.

8.5.2. **Accounting & Finance** – The ability to supervise, direct, advise, formulate policy, and account for the execution of DoD resources, including preparation of auditable financial statements. The ability to direct, supervise, and operate integrated DoD accounting and financial management systems and manage and execute financial operations that provide common DoD support in the areas of finance (payroll, commercial pay, etc.), and accounting.

Appendix B. NASA SBIR/STTR Technology Taxonomy

The following taxonomy was generated by the National Aeronautics and Space Administration (NASA) for the NASA SBIR and STTR program and featured as Appendix B of the Fiscal Year 2017 SBIR/STTR General Solicitation (NASA SBIR/STTR Program Support Office, 2017).

Table 8. NASA SBIR/STTR Taxonomy

Aeronautics/Atmospheric Vehicles
Aerodynamics
Air Transportation & Safety
Airship/Lighter-than-Air Craft
Avionics (see also Control and Monitoring)
Analysis
Analytical Instruments (Solid, Liquid, Gas, Plasma, Energy; see also Sensors)
Analytical Methods
Astronautics
Aerobraking/Aerocapture
Entry, Descent, & Landing (see also Planetary Navigation, Tracking, & Telemetry)
Navigation & Guidance
Relative Navigation (Interception, Docking, Formation Flying; see also Control & Monitoring; Planetary Navigation, Tracking, & Telemetry)
Space Transportation & Safety
Spacecraft Design, Construction, Testing, & Performance (see also Engineering; Testing & Evaluation)
Spacecraft Instrumentation & Astrionics (see also Communications; Control & Monitoring; Information Systems)
Tools/EVA Tools
Autonomous Systems
Autonomous Control (see also Control & Monitoring)
Intelligence
Man-Machine Interaction
Perception/Vision
Recovery (see also Vehicle Health Management)
Robotics (see also Control & Monitoring; Sensors)
Biological Health/Life Support
Biomass Growth
Essential Life Resources (Oxygen, Water, Nutrients)

Fire Protection
Food (Preservation, Packaging, Preparation)
Health Monitoring & Sensing (see also Sensors)
Isolation/Protection/Radiation Shielding (see also Mechanical Systems)
Medical
Physiological/Psychological Countermeasures
Protective Clothing/Space Suits/Breathing Apparatus
Remediation/Purification
Waste Storage/Treatment
Communications, Networking & Signal Transport
Ad-Hoc Networks (see also Sensors)
Amplifiers/Repeaters/Translators
Antennas
Architecture/Framework/Protocols
Cables/Fittings
Coding & Compression
Multiplexers/Demultiplexers
Network Integration
Power Combiners/Splitters
Routers, Switches
Transmitters/Receivers
Waveguides/Optical Fiber (see also Optics)
Control & Monitoring
Algorithms/Control Software & Systems (see also Autonomous Systems)
Attitude Determination & Control
Command & Control
Condition Monitoring (see also Sensors)
Process Monitoring & Control
Sequencing & Scheduling
Telemetry/Tracking (Cooperative/Noncooperative; see also Planetary Navigation, Tracking, & Telemetry)
Teleoperation
Education & Training
Mission Training
Outreach
Training Concepts & Architectures
Electronics
Circuits (including ICs; for specific applications, see e.g., Communications, Networking & Signal Transport; Control & Monitoring, Sensors)
Manufacturing Methods
Materials (Insulator, Semiconductor, Substrate)
Superconductance/Magnetics
Energy
Conversion

Distribution/Management
Generation
Sources (Renewable, Nonrenewable)
Storage
Engineering
Characterization
Models & Simulations (see also Testing & Evaluation)
Project Management
Prototyping
Quality/Reliability
Software Tools (Analysis, Design)
Support
Imaging
3D Imaging
Display
Image Analysis
Image Capture (Stills/Motion)
Image Processing
Radiography
Thermal Imaging (see also Testing & Evaluation)
Information Systems
Computer System Architectures
Data Acquisition (see also Sensors)
Data Fusion
Data Input/Output Devices (Displays, Storage)
Data Modeling (see also Testing & Evaluation)
Data Processing
Knowledge Management
Logistics
Inventory Management/Warehousing
Material Handing & Packaging
Transport/Traffic Control
Manufacturing
Crop Production (see also Biological Health/Life Support)
In Situ Manufacturing
Microfabrication (and smaller; see also Electronics; Mechanical Systems; Photonics)
Processing Methods
Resource Extraction
Materials & Compositions
Aerogels
Ceramics
Coatings/Surface Treatments
Composites

Fluids
Joining (Adhesion, Welding)
Metallics
Minerals
Nanomaterials
Nonspecified
Organics/Biomaterials/Hybrids
Polymers
Smart/Multifunctional Materials
Textiles
Mechanical Systems
Actuators & Motors
Deployment
Exciters/Igniters
Fasteners/Decouplers
Isolation/Protection/Shielding (Acoustic, Ballistic, Dust, Radiation, Thermal)
Machines/Mechanical Subsystems
Microelectromechanical Systems (MEMS) and smaller
Pressure & Vacuum Systems
Structures
Tribology
Vehicles (see also Autonomous Systems)
Microgravity
Biophysical Utilization
Optics
Adaptive Optics
Fiber (see also Communications, Networking & Signal Transport; Photonics)
Filtering
Gratings
Lenses
Mirrors
Telescope Arrays
Photonics
Detectors (see also Sensors)
Emitters
Lasers (Communication)
Lasers (Cutting & Welding)
Lasers (Guidance & Tracking)
Lasers (Ignition)
Lasers (Ladar/Lidar)
Lasers (Machining/Materials Processing)
Lasers (Measuring/Sensing)
Lasers (Medical Imaging)

Lasers (Surgical)
Lasers (Weapons)
Materials & Structures (including Optoelectronics)
Planetary Navigation, Tracking, & Telemetry
Entry, Descent, & Landing (see also Astronautics)
GPS/Radiometric (see also Sensors)
Inertial (see also Sensors)
Optical
Ranging/Tracking
Telemetry (see also Control & Monitoring)
Propulsion
Ablative Propulsion
Atmospheric Propulsion
Extravehicular Activity (EVA) Propulsion
Fuels/Propellants
Launch Engine/Booster
Maneuvering/Stationkeeping/Attitude Control Devices
Photon Sails (Solar; Laser)
Spacecraft Main Engine
Surface Propulsion
Tethers
Sensors/Transducers
Acoustic/Vibration
Biological (see also Biological Health/Life Support)
Biological Signature (i.e., Signs Of Life)
Chemical/Environmental (see also Biological Health/Life Support)
Contact/Mechanical
Electromagnetic
Inertial
Interferometric (see also Analysis)
Ionizing Radiation
Optical/Photonic (see also Photonics)
Positioning (Attitude Determination, Location X-Y-Z)
Pressure/Vacuum
Radiometric
Sensor Nodes & Webs (see also Communications, Networking & Signal Transport)
Thermal
Software Development
Development Environments
Operating Systems
Programming Languages
Verification/Validation Tools
Spectral Measurement, Imaging & Analysis (including Telescopes)

Infrared
Long
Microwave
Multispectral/Hyperspectral
Non-Electromagnetic
Radio
Terahertz (Sub-millimeter)
Ultraviolet
Visible
X-rays/Gamma Rays
Testing & Evaluation
Destructive Testing
Hardware-in-the-Loop Testing
Lifetime Testing
Nondestructive Evaluation (NDE; NDT)
Simulation & Modeling
Thermal Management & Control
Active Systems
Cryogenic/Fluid Systems
Heat Exchange
Passive Systems
Vehicle Health Management
Diagnostics/Prognostics
Recovery (see also Autonomous Systems)

Appendix C. Mapping of NASA SBIR/STTR Tech Taxonomy to 2nd Tier DoD JCAs

Table 9. Matching of NASA Taxonomy to JCA Taxonomy

Matching NASA Taxonomy to JCA Taxonomy					
DoD Joint Capability Areas		*NASA SBIR/STTR Technology Taxonomy*	DoD Joint Capability Areas		*NASA SBIR/STTR Technology Taxonomy*
1.	**Force Integration**		**5.**	**Command and Control**	
1.1	Force Management	*Education & Training*	5.1	Organize	
1.2	Force Preparation		5.2	Understand	
1.3	Building Partnerships		5.3	Plan	
2.	**Battlespace Awareness**		5.4	Decide	
2.1	Planning & Direction	*Information Systems*	5.5	Direct	
		Electronics	5.6	Monitor	*Control & Monitoring*
		Optics	**6.**	**Communications & Computers**	
		Photonics			*Communications, Networking & Signal Transport*
		Sensors/Transducers			*Optics*
2.2	Collection	*Spectral Measurement, Imaging & Analysis (including Telescopes)*	6.1	Information Transport	*Photonics*
2.3	Processing / Exploitation	*Analysis*			*Communications, Networking & Signal Transport*
2.4	Analysis, Estimation, & Production	*Information Systems*			*Electronics*
2.5	BA Dissemination & Integration	*Information Systems*	6.2	Network Management	*Information Systems*
2.6	Counterintelligence (CI)		6.3	Cybersecurity	
3.	**Force Application**		6.4	Defensive Cyberspace Operations (Internal Defensive Measures)	
		Aeronautics/Atmospheric Vehicles	6.5	Enterprise Services	*Electronics*
		Astronautics			*Information Systems*
		Autonomous Systems			*Planetary Navigation, Tracking, & Telemetry*
		Mechanical Systems			*Software Development*
		Propulsion	**7.**	**Protection**	
3.1	Maneuver	*Thermal Management & Control*	7.1	Prevention	
3.2	Fires	*Photonics*	7.2	Mitigation	
4.	**Logistics**		7.3	Recovery	
4.1	Deployment & Distribution		**8.**	**Corporate Management & Support**	
4.2	Supply		8.1	Advisory & Compliance	*Testing & Evaluation*
					Software Development
4.3	Maintenance (Depot & Field)	*Photonics*	8.2	Strategic Management	
		Vehicle Health Management	8.3	Information Management	
4.4	Logistics Services	*Logistics*			*Manufacturing*
4.5	Operational Contract Support				*Testing & Evaluation*
4.6	Engineering	*Biological Health/Life Support*			*Materials & Compositions*
			8.4	Acquisition & Technology	*Software Development*
4.7	Base & Installation Support	*Energy*	8.5	Financial Management	
4.8	Health Services	*Biological Health/Life Support*	Unmatched NASA Taxonomy		*Microgravity*

Appendix D. Final SBIR Data Set

A publicly available, redacted version of the SBIR data used for this analysis is available on the AFIT Scholar website (https://scholar.afit.edu/) under AFIT Designator Number AFIT-ENV-MS-19-M-195. The data submission consists of two files:

1) the SBIR Phase II commercialization data set used for analysis (AFIT-ENV-MS-19-M-195-SBIR DATASET.csv)
2) 2) the list of DoD SBIR topics from 1998 to 2018 used for categorical analysis (AFIT-ENV-MS-19-M-195-DOD SBIRSTTR Topics (1998-2018).xlsx).

Appendix E. Description of SBIR Data Fields

Table 10. Description of SBIR Data Fields

Column Identifier	Description	Data Source
CNTRL_NO	Control number superceeded by the proposal number as per recommendation by AFRL/SB	Phase II Data Set
PRO_NO	SBIR Phase I Proposal Number that doubles as a Control Number, recommended by AFRL/SB as best unique identifier.	Phase II Data Set
MATCH	Lists the column reference to the Commercialization Report	CCR Data Set
CCR Total Comm	References the Total Commercialization value from the Company Commercialization Report (CCR) Data Set	Excel Formula
DV_CommClosed	Verifies that a contract is a closed contract and has a total commercialization value greater than 0.	Excel Formula
DV_CommOpen	Verifies that a contract has not been closed and has a total commercialization value greater than 0.	Excel Formula
DV_ValleyofDeath	Verifies that a contract is a closed contract and has a total commercialization value of 0.	Excel Formula
TOP_NO	The originiating SBIR topic number.	Phase II Data Set
Topic Sponsor Component	References the DoD Component or Agency that soponsored the SBIR topic.	SBIR Topic Data Set
JCA	DoD Joint Capability Area (Joint Operational Need) identified during topic analysis panel exercises.	JCA Taxonomy
FY	Fiscal Year of SBIR Topic	Phase II Data Set
SOLIC_NO	SBIR Topic Solicitation Number Prefix	Phase II Data Set
AGENCY	Participating SBIR DoD SBIR Agency	Phase II Data Set
TOPIC_NO	Last 3 digits of SBIR topic number	Phase II Data Set
KEYWORDS	Keywords for SBIR contract effort, contractor (SBIR Firm) specified.	Phase II Data Set
FIELD_OFF	Partipating Managing Organization	Phase II Data Set
FIRM	Participating SBIR Firm/REDACTED	Phase II Data Set
CITY	City of SBIR Firm/REDACTED	Phase II Data Set
STATE	State of SBIR Firm/REDACTED	Phase II Data Set

ZIP	Zip of SBIR Firm/REDACTED	Phase II Data Set
ZIP4	Zip of SBIR Firm/REDACTED	Phase II Data Set
NO_EMPS	Number of employees of SBIR Firm/REDACTED	Phase II Data Set
FIRMID	SBIR Office Specific Firm ID/REDACTED	Phase II Data Set
DUNS	DUNS Code/REDACTED	Phase II Data Set
SBARegNo	SBA Registration number of SBIR Firm/REDACTED	Phase II Data Set
SIC1	Standard Industrial Classification Code (SIC) 1/REDACTED	Phase II Data Set
SIC2	Standard Industrial Classification Code (SIC) 2/REDACTED	Phase II Data Set
SIC3	Standard Industrial Classification Code (SIC) 3/REDACTED	Phase II Data Set
SIC4	Standard Industrial Classification Code (SIC) 4/REDACTED	Phase II Data Set
PRO_COST	Projected Cost of Contract	Phase II Data Set
PRO_DUR	Projected Duration of Contract	Phase II Data Set
PHASE	Phase of SBIR contract effort (should be Phase II).	Phase II Data Set
MINORITY	Indicates minority owned business status.	Phase II Data Set
WOMAN	Indicates woman owned business status.	Phase II Data Set
HUBZONE	Indicates SBA Hubzone Status	Phase II Data Set
SDVOSB	Indicates Service-Disabled Veteran Owned business status.	Phase II Data Set
PI_PCT	Not Used For Analysis	Phase II Data Set
WOMAN_PI	Not Used For Analysis	Phase II Data Set
MINORITY_PI	Not Used For Analysis	Phase II Data Set
Student_Faculty_Owned	Not Used For Analysis/REDACTED	Phase II Data Set
AFF_NAME	Not Used For Analysis/REDACTED	Phase II Data Set
AFF_ADDR1	Not Used For Analysis/REDACTED	Phase II Data Set

AFF_ADDR2	Not Used For Analysis/REDACTED	Phase II Data Set
AFF_CITY	Not Used For Analysis/REDACTED	Phase II Data Set
AFF_STATE	Not Used For Analysis/REDACTED	Phase II Data Set
AFF_ZIP	Not Used For Analysis/REDACTED	Phase II Data Set
AFF_ZIP4	Not Used For Analysis/REDACTED	Phase II Data Set
AFF_NOEMPS	Not Used For Analysis/REDACTED	Phase II Data Set
AFF_COUNTRY	Not Used For Analysis/REDACTED	Phase II Data Set
AFF_PROVINCE	Not Used For Analysis/REDACTED	Phase II Data Set
SLCT_DATE	Date of SBIR Phase II Contract Solicitation	Phase II Data Set
REC_DATE	Date of Phase II Solicitation Receival	Phase II Data Set
AWD_DATE	Date of Phase II SBIR Contract Award	Phase II Data Set
END_DATE	Date of Phase II contract closeout.	Phase II Data Set
ENDDATE_SCRUB	Calculation of contract end date, if date not specified, by adding 24 months to contract award date.	Excel Formula
DV_Closed	Verifies contract end date is before current date (July 24, 2018)	Excel Formula
DV_Open	Verifies contract end date is after current date (July 24, 2018)	Excel Formula
DV_EXCLUDEME	Verifies if contracts have a non-indicated or calculateable end date, marking them for exclusion.	Excel Formula
STATUS	Status of Phase II Contract (A for Phase II contract award)	Phase II Data Set
DV_AWD	Verifies contract was awarded.	Excel Formula
DV_FUTURAWD	Verifies contract will be awarded in the future.	Excel Formula
AWARD_AMT	Awarded amount for contract effort.	Phase II Data Set
DV_AWDCAP(PH1+2)	Verifies award amound does not exceed maximum cap as set by SBIR policy for Phase I and II efforts.	Excel Formula
AWARD AMT SCRUB	Returns award amount if award cap has not been exceeded.	Excel Formula
CONTRACT	Phase II SBIR Contract Number	Phase II Data Set

JUSTIFY	Not Used For Analysis	Phase II Data Set
JUSTIFY_NOTES	Not Used For Analysis	Phase II Data Set
FAST_TRACK	Not Used For Analysis	Phase II Data Set
PH2_ENHANCE	Indicates additional SBIR funding through the Phase II Enhancement Program	Phase II Data Set
CRP	Indicates enrollment into a Commercialization Readiness Program (CRP).	Phase II Data Set
DV_CRP	Dummy variable for statistical analysis used to signify if program is enrolled in CRP.	Excel Formula
DV_NONCRP	Dummy variable for statistical analysis used to signify if program is not enrolled in CRP.	Excel Formula
PH1CNTRLNO	Not Used For Analysis	Phase II Data Set
FY_REPORT	Not Used For Analysis	Phase II Data Set
COMMENT	Not Used For Analysis	Phase II Data Set
CAI	Not Used For Analysis	Phase II Data Set
DIRECTTOPHII	Not Used For Analysis/REDACTED	Phase II Data Set
PERF_BENCHMARK	Not Used For Analysis/REDACTED	Phase II Data Set
VC_DATABASE	Not Used For Analysis/REDACTED	Phase II Data Set
DTA	Not Used For Analysis/REDACTED	Phase II Data Set
DTA_AMOUNT	Not Used For Analysis/REDACTED	Phase II Data Set
Criminally_Liable_Flag	Not Used For Analysis/REDACTED	Phase II Data Set
CL_FIRST	Not Used For Analysis/REDACTED	Phase II Data Set
CL_MIDDLE	Not Used For Analysis/REDACTED	Phase II Data Set
CL_LAST	Not Used For Analysis/REDACTED	Phase II Data Set
CL_COMP	Not Used For Analysis/REDACTED	Phase II Data Set
SBIR_STTR	Not Used For Analysis/REDACTED	Phase II Data Set
AUTO	Not Used For Analysis/REDACTED	Phase II Data Set

Appendix F. Initial Commercialization Analysis Attempts

Overview

Multiple attempts to categorize and analyze the Small Business Innovation Research (SBIR) data set for commercialization were conducted. These attempts included regression analysis using existing data categories, contract categorization, firm categorization, and SBIR topic classification. The intent of these attempts were to provide enhance the data set so that statistical analysis of the data would provide statistically significant results by in some cases simply visual identification through scatter plot analysis or through regression analysis for the 95% significance level. These avenues of approach while deemed not appropriate for this research, do provide a “what not to do” guide for those conducting further research related to SBIR commercialization rates and this data set.

Regression Analysis Using Existing Data Categories

An initial regression analysis was conducted using categorical data already present within the existing data set. A dummy variable was established for commercialized programs and used as a response variable against present categorical data. The results of this initial analysis proved inconclusive with a significance level well below 95%. Additional categorization was required in order to conduct any sort of significant statistical analysis.

Contract Categorization

The first set of categorization attempts looked at classifying the contracts themselves, specifically keywords within the data set, location relative to a representative SBIR management office, contract award funding, and enrollment in a SBIR

Commercialization Readiness Program (CRP). The keywords within the SBIR contract data set consisted of multiple keywords per contract that were concatenated together into a single entry. The most common keywords as shown in Table 11 were extracted from the data set and used for classification. The issues with this classification method were that the keywords themselves did not follow a clear taxonomy and were entered by the contractor and not SBIR office personnel, which led to the determination that this method was not an official or reasonable source of classification data and was determined not to be a viable classification method.

The location of the SBIR effort with respect to contractor and SBIR management office was tested as a possible method of categorization. If the contractor was performing the effort for the SBIR contract and was in proximity (in the same state) as the SBIR office managing the contract, more support beneficial to the SBIR effort could be reasonably expected. SBIR contracts were analyzed for the location of the effort within the same state as the SBIR management office by comparison of indicated state or Zone Improvement Plan code. A scatter plot of commercialization rates by SBIR management offices with same state efforts was generated and is shown in Figure 21. This plot depicts a random distribution which along with a low sample size of same state efforts (less than or equal to 11 contracts each), led to the decision that this was not a viable method for analysis.

Table 11. Keyword Summary Statistics

Keyword Summary Statistics					
Category	Program Count	Commercialization Count	Comm Rate	Funding Total	Funding Average
Additive Manufacturing	10	0	0%	$ 7,765,358.00	$ 776,535.80
AI	16	3	19%	$ 13,799,640.00	$ 862,477.50
Aircraft	28	2	7%	$ 26,166,129.00	$ 934,504.61
Command and Control	27	5	19%	$ 21,898,080.00	$ 811,040.00
Communication	46	3	7%	$ 38,610,478.00	$ 839,358.22
Composite	45	4	9%	$ 32,411,763.00	$ 720,261.40
Cyber	5	0	0%	$ 3,739,183.00	$ 747,836.60
Data	39	6	15%	$ 31,400,571.00	$ 805,142.85
Displays	2	0	0%	$ 1,749,228.00	$ 874,614.00
Drone	16	1	6%	$ 15,315,386.00	$ 957,211.63
Electronic Warfare	9	0	0%	$ 6,836,502.00	$ 759,611.33
Energy	39	2	5%	$ 32,790,147.00	$ 840,773.00
Fuel	8	1	13%	$ 7,136,494.00	$ 892,061.75
ISR	8	1	13%	$ 7,502,698.00	$ 937,837.25
Landing Gear	7	4	57%	$ 4,203,168.00	$ 600,452.57
Medical	9	0	0%	$ 6,797,851.00	$ 755,316.78
Modeling & Simulation	50	3	6%	$ 41,400,419.00	$ 828,008.38
Navigation	37	1	3%	$ 29,522,937.00	$ 797,917.22
Performance	17	0	0%	$ 14,390,823.00	$ 846,519.00
Propulsion	43	3	7%	$ 32,780,159.00	$ 762,329.28
Radar	19	1	5%	$ 13,861,734.00	$ 729,564.95
Safety	35	2	6%	$ 30,156,005.00	$ 861,600.14
Satellite	24	0	0%	$ 20,475,949.00	$ 853,164.54
Sensor	122	9	7%	$ 97,052,178.00	$ 795,509.66
Situational Awareness	18	2	11%	$ 15,676,131.00	$ 870,896.17
Software	12	0	0%	$ 10,200,446.00	$ 850,037.17
Sustainment	56	4	7%	$ 48,919,547.00	$ 873,563.34
Test	12	0	0%	$ 7,691,797.00	$ 640,983.08
Thermal	16	2	13%	$ 12,206,168.00	$ 762,885.50

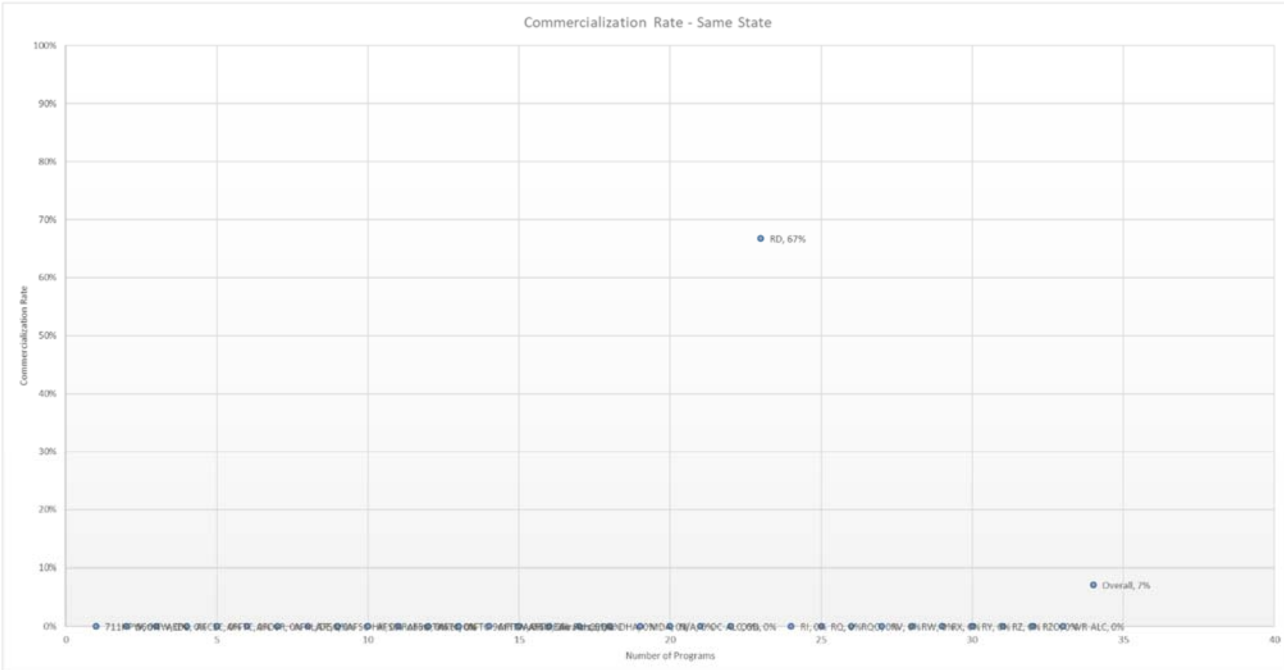

Figure 21. Commercialization Rate for Same State SBIR Efforts

The level of funding for a SBIR contract effort was viewed as a possible factor for SBIR commercialization. The data set had already been scrubbed for and excluded 7 SBIR contracts that exceeded the maximum allowable funding level of $1,885,450.50. The resulting contracts had a maximum funding level of $1,839,909, a minimum funding level of $49,966, and an average funding level of $816,199. SBIR funding categories were generated within $50,000 increments and resulted in 37 categories that spanned from $0 to $1,850,000. A scatter plot was generated to compare commercialization rates by funding level and is shown in Figure 22**.** The random distribution depicted within the scatter plot resulted in the determination that this was not a viable categorization method.

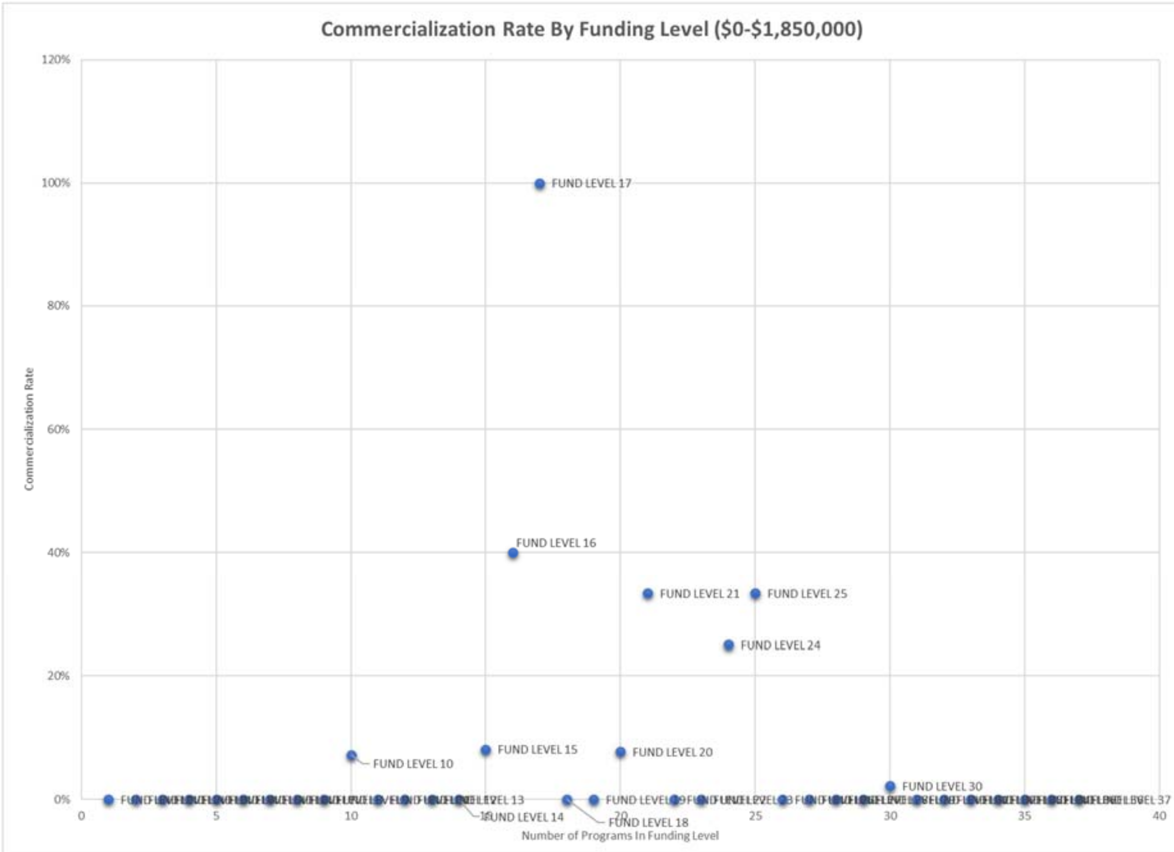

Figure 22. Commercialization Rate by Funding Level

Commercialization Readiness Programs (CRPs) are a DoD initiative and aim to assist SBIR firms navigate through the SBIR process. Enrollment within a CRP was viewed as a possible factor in determining commercialization of a SBIR contract. A dummy variable was generated for contracts that were indicated within the dataset as being enrolled in a CRP. The commercialization rates for all programs were compared to those enrolled and not enrolled in a CRP. These metrics as well as the percent of programs within the dataset reported as being part of a CRP are shown in Figure 23. While there appears to be a difference of commercialization rates (1%) for CRP enrollment, only 2% of programs within the dataset were indicated as being enrolled.

This small percentage of enrollment leads to the conclusion that CRP enrollment within the data set is most likely heavily underreported and is not a viable method for determining commercialization.

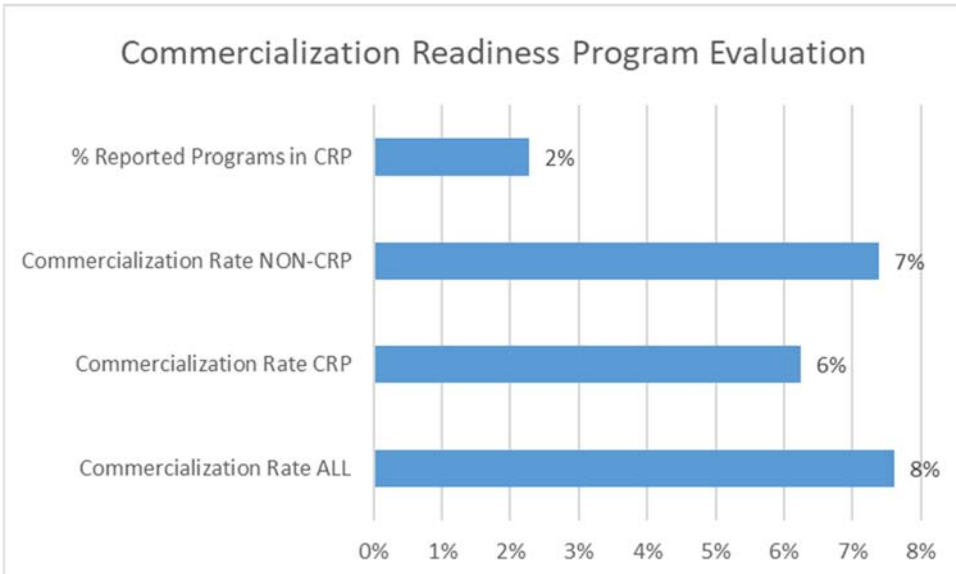

Figure 23. Commercialization Readiness Program Evaluation

Firm Categorization

The focus of categorization shifted from the individual contract efforts to the firms themselves, SBIR firms are small businesses that would logically follow a specific industry/technology specialization. The size of the firm itself conducting the effort as well as the firm's specialization were viewed as possible factors for commercialization. The SBIR firms completing contract efforts within the data set ranged from 1 to 518 employees, these firms were grouped into 20 different size categories. Commercialization rates by firm size category were plotted against each other and shown in Figure 24. The random distribution of the plot and the appearance of only one outlier indicates that firm size is not a significant factor in determining commercialization.

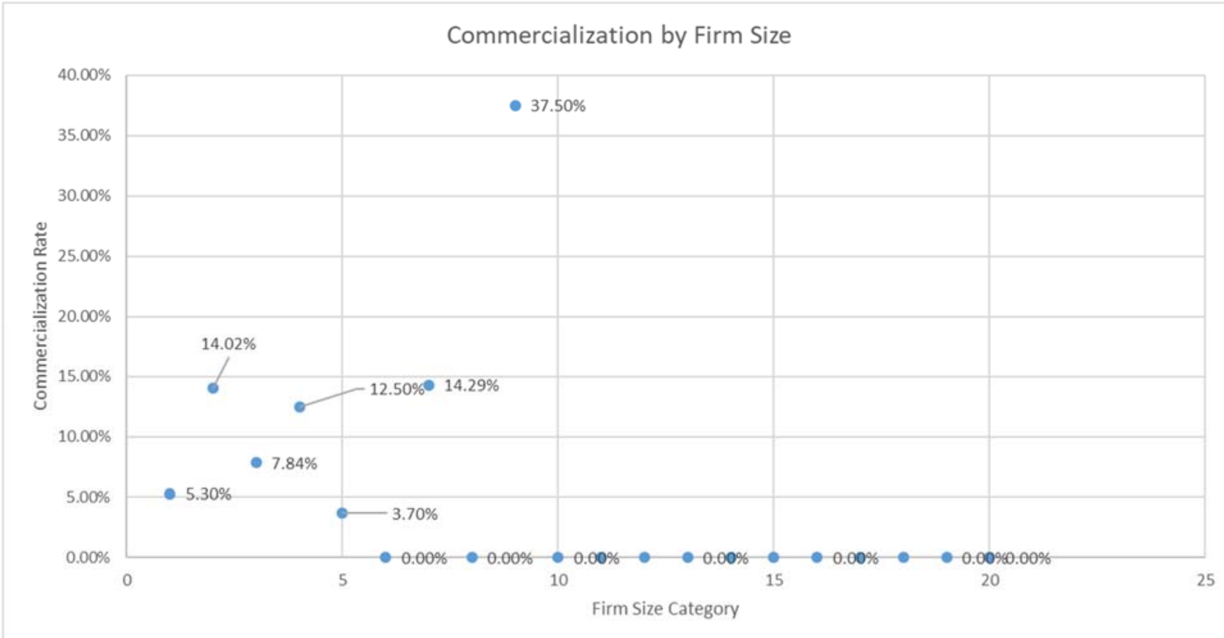

Figure 24. Commercialization by Firm Size

The specialization of the SBIR firm completing the contract effort was viewed as a possible form of categorization. By viewing firm data available within the data set as well as through cross-reference searches of SBIR forms with the United States Government System (USG) for Award Management (SAM) database, three forms of specialization codes were obtained: North American Industrial Classification (NAIC) codes, Product Service Codes (PSCs), and Standard Industrial Classification (SIC) codes. These codes are prevalent within acquisitions, contracting, and logistics for the Department of Defense and the USG. Unfortunately, these classification systems do not share that applicability with the state-of-the-art nature of the SBIR program, these codes focus on delivery of current technology product. SBIR focuses more on future technology and research (a rather intangible product) which led to the observance of common classifications among all SBIR firms for all 3 classification systems. Examples of this include the NACIS code Engineering Services referenced by 254 firms and the SIC code Services-Commercial, Physical, and Biological referenced by 198 firms. This lack of specialization between firms led to the determination that these classification systems are not adequate for an individual SBIR effort, they cannot be used to adequately classify each SBIR effort.

SBIR Topic Classification

The classification effort refocused towards the SBIR topics that generated the contract efforts themselves. These SBIR topics are generated from within the DoD by the efforts of Sponsoring Organizations, Managing Organizations, and the AFRL/SB office that manages the overall Air Force SBIR program. Any information such as key words or descriptions would be the product of the Department of Defense and free from contractor input. Several contracts can be generated per one SBIR topic and each component or DoD entity can choose to award a SBIR contract for another's efforts. Several classification methods were viewed as possible solutions for classifying the SBIR contract efforts: internal classification within the SBIR topics, Department of Defense component ownership, SBIR topic taxonomy generation, and the Joint Capability Area classification system currently utilized in this research effort. The JCA effort was discussed over the course of this paper and will not be included in this appendix.

The SBIR topic dataset contained an internal coding scheme that included fields such as "Info Systems", "Sensors", and "Nuclear". The coding of each topic was remapped to the SBIR program contract data and a set of summary statistics was generated as shown in Table 12. The coding scheme was determined inadequate for analysis due to a lack of mutual exclusivity and exhaustiveness. Several topics contained multiple coding assignments such as a sensing system being coded as “Sensors” and “Electronics”. The total number of SBIR programs referenced by the internal coding was only 690 out of total of 706 programs.

Table 9. Summary Statistics of Data Set from SBIR Topic Categorization

Summary Statistics of Data Set from SBIR Topic Categorization					
Category	Number of SBIR Programs	Commercialized Programs	Commercialization Rate	Dollar Value	Commercialized Dollars
Air Platform	30	5	17%	$ 23,528,553.00	$ 1,193,545.00
Chem_Bio Defense	98	8	8%	$ 79,564,807.00	$ 890,779.00
Info Systems	1	0	0%	$ 978,094.00	$ -
Ground Sea	84	5	6%	$ 68,482,406.00	$ 1,809,048.00
Materials	7	0	0%	$ 7,166,097.00	$ -
Bio Medical	106	10	0%	$ 89,951,847.00	$ 7,060,011.00
Sensors	0	0	0%	$ -	$ -
Electronics	75	8	11%	$ 62,294,734.00	$ 7,085,107.00
Battlespace	41	6	15%	$ 33,140,570.00	$ 3,871,777.00
Space Platforms	14	2	14%	$ 15,405,080.00	$ 1,030,000.00
Human Systems	74	4	5%	$ 65,127,499.00	$ 6,001,046.00
Weapons	36	1	3%	$ 31,146,750.00	$ 2,800,047.00
Nuclear	40	3	8%	$ 33,239,692.00	$ 907,396.00
TOTAL	**606**	**52**			
Total SBIR Contracts	**706**	**147**			

The SBIR topic data indicated the owning Department of Defense component for that topic. The data set contained topics from the Air Force but also from other components such as the Army, Navy, Missile Defense Agency, and the Office of the Secretary of Defense. A component sponsoring its own topic compared to another component could be a useful factor for commercialization. When comparing the number of contracts between each component as shown in Table 13, an extremely disproportionate contract population exists for each component as compared to the Air Force, resulting in component ownership being a poor factor in determining commercialization.

Table 10. DoD Component Topic Summary

Component Topic Summary					
Component	Number of Contracts	Commercialized Contracts	Commercialization Rate	Total Dollar Value of Contracts	Avg Pgm Dollar Value
Department of the Army	3	0	0%	$ 3,242,938.00	$ 1,080,979.33
Department of the Air Force	484	40	8%	$ 381,918,743.00	$ 789,088.31
MDA	4	0	0%	$ 4,237,910.00	$ 1,059,477.50
Department of the Navy	7	0	0%	$ 9,127,728.00	$ 1,303,961.14
Office of the Secretary of Defense	19	0	0%	$ 19,524,330.00	$ 1,027,596.32
Note: Figures represent contracts under Air Force SBIR that were derived from Topics owned by each DoD Component.					

Several taxonomy systems were generated to attempt to classify each SBIR topic. The taxonomy system (PSC based) from the August 2012 Office of the Secretary of Defense Memo: Taxonomy for the Classification of Services and Supplies & Equipment, was applied to the dataset. This PSC based system had the similar lack of state-of-the-art applicability as the SBIR firm PSCs. Through a visual analysis of the SBIR topic data two rough order of magnitude classification systems were developed. The first system relied on three categories of classification: area of interest (e.g. sensor), unique item characteristic (e.g. infrared), and specialty area (e.g. space). The second system followed a systems engineering approach with 5 areas of classification: form (e.g. infrared sensor) , fit (e.g. satellite), function (e.g. detection), environment (e.g. hypersonic), and actors (e.g. manned versus autonomous). Both systems were considered highly subjective, were not based on a clear classification list, and failed to provide a clear relation to Air Force mission sets or capabilities. These issues led to the determination to seek out another form of classification system that could attempt to resolve these issues, the Joint Capability Areas Taxonomy developed by the Joint Staff of the Department of Defense.

Appendix G. Joint Capability Area Coding Test Rules of Engagement

Joint Capability Area Taxonomy to SBIR Topic Classification Rules of Engagement

Background

The Air Force Small Business Innovation Research (SBIR) Program provides research and development funding to small businesses with the intent that these technologies will be developed into a commercially viable product. The current commercialization data set of SBIR programs lacks an adequate categorization tool to identify trends in commercialization performance behavior. The ability to categorize the SBIR topics from which the SBIR programs have been generated is the subject of this exercise. The taxonomy selected for categorization is the Department of Defense Joint Capability Area taxonomy. Joint Capability Areas (JCAs) are a set of functional categories that "minimize redundancies in capability decomposition, provide clearer boundaries to assign weapon systems, and improve management ability to develop and implement capabilities planning" (Department of Defense Joint Staff J8, 2018).

Justification

"Internal consistency, such as interrater reliability, refers to the degree to which responses to items in a test agree with one another." (Weathington, Cunningham, & Pittenger, 2012). Your JCA assignment responses will be compared to the results of others with various levels of experience to determine how consistent, or reliable, JCA assignment is for SBIR topics.

Rules of Engagement

- A sample of SBIR Topics (20 topics) have been provided with a comprehensive list of JCA definitions.
    - SBIR topics contain multiple fields such as title, objective, description, and keywords
    - While the JCA list is comprehensive, it is not considered exhaustive for the sake of this exercise.
    - An excel formatted list of the JCAs will be provided
- Each SBIR topic data set contains 6 fields for completion.
    - The first 5 fields may be assigned 0 to 5 JCA listing assignments as per your discretion
    - A sixth field is available for a “new capability”, which is capability demonstrated by the topic technology that is not contained within the JCA.
    - Multiple JCAs and/or new capabilities can be assigned to the same SBIR topic.
- You are free to complete the list of SBIR Topics in any order.
- When inputting JCA entries, enter the numbered listing (2.2.4) rather than the JCA title (Open Source Collection).
    - Your JCA entry should be to the third tertiary level (enter 2.2.4 AND 2.2.5 rather than only 2.2)
- The new capabilities field will not follow the numbered listing format, rather the name and/or description of that capability will be listed in that field.
- The concern of this exercise is the capability delivered by the SBIR topic technology (function), the device/method used to deliver that capability (form) should not be considered during JCA assignment.
- Example classifications are located on page 3 of this document.

Thank You for Your Help!

Example

Classifications:

Topic Number	Topic Title	JCA 1	JCA 2	JCA 3	JC			Objective
AF093-114	Peel and Stick Adhesive for Outer Mold Line (OML) Material Repair	4.3.4						Develop pressure sensitive adhesives (PSA) that will reduce the maintenance downtime required to join extruded polymer parts to military aircraft panels.
AF141-121	Satellite Threat Indications and Notification (TIN) in support of Space Situational Assessment	2.4.1					Machine Learning/Cognitition	Develop algorithms to determine and assess space system threats and anomalies. The ability to differentiate anomalous conditions and to correctly assess man made threats and/or abnormal environment impacts is critical for future space systems.
AF141-096	Radiation Hardened Memory							Develop a power efficient, high speed, radiation hardened

Maintenance Repair Adhesive that provides a repair capability assigned to Repair JCA (Single JCA)

Machine Learning Software that provides space situational awareness capability assigned to battlespace awareness JCA and new JCA machine learning (Single JCA with New JCA Assignment)

Memory Device for Space Missions assigned to Force Application-Maneuver-Space JCA for enabling space operation capability, Communications-Info Transport-Wireless Transmission JCA for enabling comm capability, Battlespace Awareness-Collection-Imagery JCA for enabling space sensor capability and assigned new JCA Data Storage. (Multi JCA with New JCA Assignment)

Figure 25. JCA Single Rater Exercise Assignment Example

Appendix H. Single Rater JCA Exercise Results and Reliability Calculation

Single Rater Ratings

Table 11. Single Rater JCA Ratings: Input A

Input A									
Topic Number	DV Exp >20yrs	DV Exp <5yrs	Best Fitting JCA	JCA 1	JCA 2	JCA 3	JCA 4	JCA 5	New JCA
AF141-056		1	3.1.5	5.3.1	5.2.2	2.4.3	3.1.5	5.3.5	
AF131-045		1	2.2.3	2.2.3					
AF161-107		1	6.5.3	6.5.3					
AF161-051		1	6.2.3	6.2.3	6.2.2				
AF151-108		1	7.1.3	7.2.2	7.1.3			7.1.3	
AF141-243		1	3.1.2	3.1.2	6.1.2				
AF161-021		1	4.3.1	4.3.1					Additive Manufacturing
OSD13-C05		1	8.4.3	8.4.3					Automation, Nanophotonics
AF151-061		1	8.4.2	4.6.1	8.4.2	8.4.3			
AF131-163		1	5.3.1	4.6.1	5.3.1				
AF161-093		1	3.1.2	6.4.2	3.1.2				Additive Manufacturing
AF151-067		1	3.1.2	3.1.2	6.4.2				
AF153-004		1	4.1.2	4.1.2					Additive Manufacturing
AF161-035		1	2.3.1	2.3.1					
AF161-112		1	4.1.2	4.1.2					
AF131-190		1	4.3.4	4.3.4					
AF141-182		1	2.2.2	2.2.2					
AF083-193		1	6.1.2	6.1.2					
AF131-198		1	4.2.1	4.2.1	8.4.4				
AF163-D001		1	3.1.2	3.1.2	2.2.1	2.2.2	2.2.3		

Table 12. Single Rater JCA Ratings: Input B

Input B									
Topic Number	DV Exp >20yrs	DV Exp <5yrs	Best Fitting JCA	JCA 1	JCA 2	JCA 3	JCA 4	JCA 5	New JCA
AF141-056		1	8.4.3	4.3.1	4.3.2	8.1.5	8.4.3	8.4.4	
AF131-045		1	6.1.2	6.1.2					
AF161-107		1	8.4.3	3.2.1	8.4.3				
AF161-051		1	6.1.2	6.1.2	6.2.2				
AF151-108		1	2.3.1	7.1.2	7.1.3	2.3.1	2.3.2	2.3.3	
AF141-243		1	6.5.4	6.5.4	7.2.7				
AF161-021		1	4.3.1	4.3.1	4.3.4				Additive Manufacturing
OSD13-C05		1	8.4.3	6.1.2	8.4.3				
AF151-061		1	3.1.1	3.1.1	3.1.2	3.1.3	3.1.4		
AF131-163		1	4.3.1	4.3.1	8.4.3				
AF161-093		1	3.1.2	3.1.2					Additive Manufacturing
AF151-067		1	3.1.2	3.1.2					
AF153-004		1	4.3.4	4.3.4	3.1.1	3.1.2	3.1.3	3.1.4	Additive Manufacturing
AF161-035		1	2.3.1	2.2.2	2.3.1	2.3.2			
AF161-112		1	4.3.1	3.2.1	4.3.1				
AF131-190		1	4.3.4	4.3.3	4.3.4				
AF141-182		1	2.2.2	2.2.2					
AF083-193		1	6.1.2	6.1.2					
AF131-198		1	4.3.3	4.3.4					
AF163-D001		1	2.2.2	2.2.2	2.3.1	2.3.2	5.2.1	5.2.2	

Table 13. Single Rater JCA Ratings: Input C

Input C									
Topic Number	DV Exp >20yrs	DV Exp <5yrs	Best Fitting JCA	JCA 1	JCA 2	JCA 3	JCA 4	JCA 5	New JCA
AF141-056		1	8.4.3	8.4.3					
AF131-045		1	6.1.2	6.1.2					
AF161-107		1	2.4.1	2.4.1					
AF161-051		1	6.2.3	6.2.3	6.2.2				
AF151-108		1	7.1.3	7.1.3					
AF141-243		1	6.5.4	6.5.4					
AF161-021		1	4.3.1	4.3.1					
OSD13-C05		1	6.1.2	6.1.2					
AF151-061		1	3.1.1	3.1.1					
AF131-163		1	4.3.3	4.3.3					
AF161-093		1	8.4.4	8.4.4					
AF151-067		1	3.1.2	3.1.2					
AF153-004		1	4.3.3	4.3.3					
AF161-035		1	6.5.4	6.5.4					
AF161-112		1	2.2.3	2.2.3					
AF131-190		1	4.3.4	4.3.4					
AF141-182		1	2.2.2	2.2.2					
AF083-193		1	6.1.2	6.1.2					
AF131-198		1	4.3.3	4.3.3					
AF163-D001		1	2.2.2	2.2.2					

Table 14. Single Rater JCA Ratings: Input D

Input D									
Topic Number	DV Exp >20yrs	DV Exp <5yrs	Best Fitting JCA	JCA 1	JCA 2	JCA 3	JCA 4	JCA 5	New JCA
AF141-056	1		8.4.3	8.4.3					Automation
AF131-045	1		6.1.2	6.1.2					
AF161-107	1		2.4.3	2.4.3	5.6.2				Big Data
AF161-051	1		6.1.2	6.1.2	6.2.1				
AF151-108	1		2.2.3	2.2.3					
AF141-243	1		6.5.4	6.5.4					
AF161-021	1		4.3.1	4.3.1					
OSD13-C05	1			New JCA Only, BUT Still a SINGLE JCA					Simulation
AF151-061	1		3.1.1	3.1.1					
AF131-163	1		4.3.1	4.3.1					
AF161-093	1		3.1.2	3.1.2					Manufacturing
AF151-067	1		3.1.2	3.1.2					
AF153-004	1		4.3.4	4.3.4					
AF161-035	1		2.3.1	2.3.1					
AF161-112	1		4.3.1	4.3.1					
AF131-190	1		4.3.4	4.3.4					
AF141-182	1		2.2.2	2.2.2					
AF083-193	1		6.1.2	6.1.2					
AF131-198	1		4.3.5	4.3.5					
AF163-D001	1		2.2.2.1	2.2.2.1					

Table 15. Single Rater JCA Ratings: Input E

Input E									
Topic Number	DV Exp >20yrs	DV Exp <5yrs	Best Fitting JCA	JCA 1	JCA 2	JCA 3	JCA 4	JCA 5	New JCA
AF141-056	1		8.4.3	8.4.3	6.3.2	6.5.3	6.3.3		
AF131-045	1		6.1.2	6.1.2					
AF161-107	1		8.4.3	8.4.3					
AF161-051	1		6.1.2	6.1.2					
AF151-108	1		7.1.3	7.1.3					
AF141-243	1		6.1.2	6.1.2					
AF161-021	1		8.4.3	8.4.3					
OSD13-C05	1		8.4.3	8.4.3					
AF151-061	1		8.4.1	8.4.1					
AF131-163	1		8.4.3	8.4.3	4.3.4				
AF161-093	1		8.4.2	8.4.2					
AF151-067	1		8.4.2	8.4.2					
AF153-004	1		4.1.2	4.1.2	4.6.1				
AF161-035	1		2.3.1	2.3.1					
AF161-112	1		4.6.1	4.6.1					
AF131-190	1		4.6.1	4.6.1					
AF141-182	1		2.2.2	2.2.2					
AF083-193	1		2.5.1	2.5.1	6.1.2				
AF131-198	1		4.6.1	4.6.1	8.4.1				
AF163-D001	1		2.2.1	2.2.1					

Interrater Reliability Calculations

Single “Best Fitting” JCA Assignment

Setup Data:

Table 16. Kappa Calculation Setup Data: Single JCA Assignment

Inter-Rater Agreement Terminology Values	Symbol	Value	Related Index
Number of Subjects "Topics"	N	20	i=1……N
Number of Experts	n	5	NA
Number of Rate Lvls	k	144	j=1…..K
Number of experts who assigned the i-th use case to the j-th rating level	nij	0-30	NA

Observed Agreement:

Table 17. Single JCA Assignment Observed Agreement

Topic Number	Value
AF141-056	0.6
AF131-045	0.6
AF161-107	0.1
AF161-051	0.4
AF151-108	0.3
AF141-243	0.3
AF161-021	0.6
OSD13-C05	0.3
AF151-061	0.3
AF131-163	0.1
AF161-093	0.3
AF151-067	0.6
AF153-004	0.2
AF161-035	0.6
AF161-112	0.1

AF131-190	0.6
AF141-182	1
AF083-193	1
AF131-198	0.1
AF163-D001	0.1

Proportion of Ratings to Rating Level:

Table 18. Single vs. Multi JCA Assignment Proportions

Joint Capability Area	Proportional Ratings
1.1.1	0
1.1.2	0
1.1.3	0
1.1.4	0
1.1.5	0
1.2.1	0
1.2.2	0
1.2.3	0
1.2.4	0
1.2.5	0
1.2.6	0
1.2.7	0
1.3.1	0
1.3.2	0
1.3.3	0
1.3.4	0
2.1.1	0
2.1.2	0
2.1.3	0
2.2.1	0.01
2.2.2	0.07
2.2.3	0.03
2.2.4	0
2.2.5	0
2.3.1	0.05
2.3.2	0
2.3.3	0
2.4.1	0.01

2.4.2	0
2.4.3	0.01
2.4.4	0
2.4.5	0
2.5.1	0.01
2.5.2	0
2.6.1	0
2.6.2	0
3.1.1	0.03
3.1.2	0.09
3.1.3	0
3.1.4	0
3.1.5	0.01
3.1.6	0
3.2.1	0
3.2.2	0
3.2.3	0
4.1.1	0
4.1.2	0.03
4.2.1	0.01
4.2.2	0
4.2.3	0
4.3.1	0.08
4.3.2	0
4.3.3	0.04
4.3.4	0.07
4.3.5	0.01
4.3.6	0
4.3.7	0
4.4.1	0
4.4.2	0
4.4.3	0
4.4.4	0
4.4.5	0
4.5.1	0
4.5.2	0
4.6.1	0.04
4.6.2	0
4.6.3	0
4.7.1	0

4.7.2	0
4.8.1	0
4.8.2	0
5.1.1	0
5.1.2	0
5.1.3	0
5.2.1	0
5.2.2	0
5.2.3	0
5.3.1	0.01
5.3.2	0
5.3.3	0
5.3.4	0
5.3.5	0
5.4.1	0
5.4.2	0
5.4.3	0
5.4.4	0
5.5.1	0
5.5.2	0
5.5.3	0
5.6.1	0
5.6.2	0
5.6.3	0
5.6.4	0
6.1.1	0
6.1.2	0.14
6.1.3	0
6.2.1	0
6.2.2	0
6.2.3	0.02
6.3.1	0
6.3.2	0.01
6.3.3	0.01
6.3.4	0
6.3.5	0
6.3.6	0
6.4.1	0
6.5.1	0
6.5.2	0

6.5.3	0.02
6.5.4	0.04
7.1.1	0
7.1.2	0
7.1.3	0.03
7.1.4	0
7.2.1	0
7.2.2	0
7.2.3	0
7.2.4	0
7.2.5	0
7.2.6	0
7.2.7	0
7.2.8	0
7.2.9	0
7.3.1	0
7.3.2	0
8.1.1	0
8.1.2	0
8.1.3	0
8.1.4	0
8.1.5	0
8.2.1	0
8.2.2	0
8.2.3	0
8.2.4	0
8.2.5	0
8.2.6	0
8.3	0
8.4.1	0.02
8.4.2	0.03
8.4.3	0.11
8.4.4	0.01
8.5.1	0
8.5.2	0

Overall Observed Limit: 0.41
Agreement by Chance: 0.0701
Kappa Coefficient: 0.365523175
Determination: Fair Agreement

Single Versus Multiple JCA Assignment

Setup Data:

Table 19. Kappa Calculation Setup Data: Single Versus Multi JCA Assignment

Inter-Rater Agreement Terminology Values	Symbol	Value	Related Index
Number of Subjects "Topics"	N	20	i=1……N
Number of Experts	n	5	NA
Number of Rate Lvls	k	2	j=1…..K
Number of experts who assigned the i-th use case to the j-th rating level	nij	0-30	NA

Observed Agreement:

Table 20. Observed Agreement Table for Single versus Multi JCA Assignment

SBIR Topic	Agreement
AF141-056	0.4
AF131-045	1
AF161-107	0.4
AF161-051	0.6
AF151-108	0.4
AF141-243	0.4
AF161-021	0.6
OSD13-C05	0.6
AF151-061	0.4
AF131-163	0.4
AF161-093	0.6
AF151-067	0.6
AF153-004	0.4
AF161-035	0.6
AF161-112	0.6
AF131-190	0.6
AF141-182	1
AF083-193	0.6

AF131-198	0.4
AF163-D001	0.4

Proportion of Ratings to Rating Level:

Single: 0.68

Multi: 0.32

Overall Observed Limit: 0.55

Agreement by Chance:

Single: 0.4624

Multi: 0.102

Kappa Coefficient: -0.034007353

Determination: Poor Agreement

Assigning a New Capability (New JCA)

Setup Data:

Table 21. Kappa Calculation Setup Data: New JCA Assignment

Inter-Rater Agreement Terminology Values	Symbol	Value	Related Index
Number of Subjects "Topics"	N	20	i=1……N
Number of Experts	n	5	NA
Number of Rate Lvls	k	2	j=1…..K
Number of experts who assigned the i-th use case to the j-th rating level	nij	0-30	NA

Observed Agreement:

Topic Number	Agreement
AF141-056	0.6
AF131-045	1
AF161-107	0.6
AF161-051	1
AF151-108	1
AF141-243	1
AF161-021	0.4
OSD13-C05	0.4
AF151-061	1
AF131-163	1
AF161-093	0.4
AF151-067	1
AF153-004	0.4
AF161-035	1
AF161-112	1
AF131-190	1
AF141-182	1
AF083-193	1
AF131-198	1
AF163-D001	1

Proportion of Ratings to Rating Level:

New JCA Assigned: 0.11
No New JCA Assigned: 0.89
Overall Observed Limit: 0.84
Agreement by Chance: 0.8042
Kappa Coefficient: 0.182839632
Determination: Slight Agreement

Appendix I. List of Sampled SBIR Topics for JCA Assignment

Table 22. List of Sampled SBIR Topics with Assigned JCAs

Number	SBIR Topic Number	Title	JCA Assigned	Secondary	Argument	JCA Addition Request	Notes
1	A09-004	Solid State Infrared Flare	711			CSAR Not an explicit JCA	
2	A09-099	Optimally Designed Wireless Seismic/Acoustic Ordnance Impact Characterization System	815				
3	A11-028	Asynchronous Network Signal Sensing and Classification Techniques	231				
4	AF03T017	Wireless Technology for Structural-Health Monitoring	431				
5	AF05-093	Secure TCP/IP Broadcast/Multicast	612				
6	AF05-131	Robust Solid Lubricant Coating for Gears of Cryogenic Fuel Turbopumps	312				
7	AF05-265	Next Generation Aircraft Depot Maintenance	43	823			

		Management Technologies						
8	AF05-273	Automated Delivery of Pigmentation for Camouflaging Patterns for Composite Shelters	711					
9	AF06-019	Photosensitive Visor for Flight Helmets	729		1			
10	AF06-300	Hypervelocity Projectile Position, Angle of Attack, and Velocity Detection System	223					
11	AF06-320	Ground Loads Predictive Analysis	843					
12	AF071-117	In-Process Cure Monitoring of Specialty Material Coatings	433					
13	AF071-213	False Alarm Rejection (FAR) Techniques for Missile Warning Systems (MWSs)	713					
14	AF071-320	Development of Cad Plating Replacement with Zinc Nickel on High Strength Steel Components	433					
15	AF073-051	Test Method for Inducing Steep Thermal Gradients in	843	841				

		Thin-Walled Structures						
16	AF073-105	Just In Time (JIT) Component Presentation	422					
17	AF073-131	Cryo-Motion for Space Simulation Testing	843					
18	AF073-142	Aeroelastic Model Updating	843					
19	AF083-193	Bandwidth Efficient SATCOM Waveform Techniques	612					
20	AF083-198	Low-Cost Deorbiting System	312					
21	AF083-254	Portable Missile Miss-Distance Identification System (PMMDIS)	815	843				
22	AF093-025	Visualization of Cross-Domain C2ISR Operations	52					
23	AF093-070	Miniaturized Satellite Development for Responsive Space Missions	842					Too Broad
24	AF093-114	Peel and Stick Adhesive for Outer Mold Line (OML) Material Repair	434					
25	AF093-165	Robust Spark and Plasma Ignition Systems for Gas Turbine Main Combustors	311	313				Could be land and sea

		and Augmentors						
26	AF093-191	Non-Intrusive Direct Part Marking	421					
27	AF093-208	Expert Troubleshooting Technology for Rapidly Diagnosing Failures in Complex Systems	431					
28	AF093-216	Broadband Infrared Coherent Fiber Image Guide	311	222				
29	AF09-BT22	Nanoscale Conformable Thermal Interface Materials with Electronically Enhanced Heat Conduction	842					Hypersonics
30	AF103-017	Multi-Frame Blind Deconvolution Algorithms for Daylight and Strong Turbulence Imaging	231					
31	AF103-064	Multi-Sensor Space Object Tracking	24					Doing many functions
32	AF103-088	Threat Assessment Sensor Suite (TASS)	24					
33	AF103-089	Improved Solar Cell Power for Cubesats	312					
34	AF103-102	Spacecraft Integrated-Power and	312					

		Attitude-Control System						
35	AF103-180	Cognitive Multi-Sensor Improvised Explosive Device (IED) Detection Technologies (COMIDT)	462					
36	AF103-198	High Temperature Blade Health Measurement System for Adaptive Engines	431	311				
37	AF103-208	Variable-Fidelity Toolset for Dynamic Thermal Modeling and Simulation of Aircraft Thermal Management System (TMSs)	843					
38	AF103-209	Internal Combustion (IC) Engine/Electric Hybrid Power/Propulsion System for Small Unmanned Aerial Vehicles (UAVs)	311					
39	AF103-224	Infrared Spectrometer for the Cryovacuum Environment	312					
40	AF103-240	UNIVERSAL FLEXIBLE COIL EDDY CURRENT PROBE	431					

41	AF103-253	Honeycomb Sandwich Structure Inspection	431				
42	AF112-026	Cognitive Approaches to Integrated Intelligence Production	24				Doing many functions
43	AF112-043	High-Speed Data Transmission in Multimode Fiber	311	611	1		
44	AF112-055	Ensuring Optimal and Secure Routes, Packet Forwarding and Spectrum Utilization through Synthesis of Tactical Wireless Broadband Systems	62				Doing many functions
45	AF112-097	Laser Designator Beam Line Stabilization	321				
46	AF112-170	Extended Endurance System Integration in an Air-launched Expendable Small Remotely Piloted Aircraft (RPA)	311				
47	AF112-219	Solar and Waste Heat Powered Environmental Control for Buildings	472				

48	AF11-BT25	Electrode Surface Erosion at High Pressures	432				
49	AF121-050	Link Analysis of Knowledge Derived from Social Media Sources	231				
50	AF121-095	Mobile Target Secondary Debris (MTSD)	722				
51	AF121-097	Weapon Burial Secondary Debris (WBSD)	722				
52	AF121-112	Near-Surface Residual Stress Measurements for Aerospace Structures	431				
53	AF121-156	Power Efficient Software Defined Radio (SDR) Mobile Architecture Technology for Handheld Devices	612	654			
54	AF121-170	Prognostics Approaches for Remote Piloted Aircraft (RPA) Propulsion and Vehicle Systems in Harsh Environments	431				
55	AF121-187	Reconstruction Algorithms for High-Energy Computed Tomography Images of Rocket Motors	431				
56	AF121-189	Novel Engine Cycles for Upper Stage	312				

		Liquid Rocket Engines						
57	AF121-212	Re-evaluation of Oil Analysis Program	42	825				Doing many functions
58	AF121-214	Wireless Technology for Probes and Accessories for Nondestructive Inspection Testing Instruments	431					
59	AF121-225	Just In Time (JIT) Aircraft Maintenance System	43					Doing many functions
60	AF131-023	Holographic Video Display (HVD)	245	842				
61	AF131-038	Validation of Automatic Ground Moving Target Indicator Exploitation Algorithms	232					
62	AF131-045	Ground Based Sensor for measurement of V and W band satellite link propagation channel	612					
63	AF131-050	SATCOM Wideband digital channel analyzer	612					
64	AF131-052	Cross Domain Dissemination	631	523				
65	AF131-057	Automated Analog Electronics Design Tools for Obsolete Parts	422					

66	AF131-060	W and V Band Satellite Transceiver	612				
67	AF131-062	Cooperative Networked GPS signal acquisition	654				
68	AF131-066	Multiband Metasurface for Reduced Antenna Footprint and Jamming Mitigation	727				
69	AF131-067	Software-Only Front-End Processors for Satellite Command and Control	312				
70	AF131-069	AFSCN Mission Planning and scheduling tool	532				
71	AF131-074	Ultra-efficient Thermoelectric Cooling Module for Satellite Thermal Management	312				
72	AF131-077	High Performance Separable Thermal Mechanical Interface for Electronics	312				
73	AF131-079	Ka-band Satellite Phased Array Antenna	612				
74	AF131-082	Radiation Hardened Carbon Nanotube-based Nonvolatile Memory	312				

75	AF131-131	Group 4-5 UAS integration of terminal area sensors & operations in the terminal area for Airborne Sense and Avoid	311				
76	AF131-135	Fully Adaptive Radar	222				
77	AF131-139	GMTI Data Exploitation for SWAP Limited Radar Systems	232				
78	AF131-142	Packaging High Power Photodetectors for 100 MHz to 100 GHz RF Photonic Applications	612				
79	AF131-158	Cetane Sensor for Remotely Piloted Aircraft (RPA) Propulsion Systems that Operate on Heavy Fuel	311				
80	AF131-159	Innovative Hybrid Power System for Increased Endurance Rapid Response Small Unmanned Aerial Systems (SUAS)	311				
81	AF131-160	Advanced Propulsion and Power Concepts for Large Size Class Unmanned	311				

		Aerial Systems (UAS)					
82	AF131-163	Bearing Analytical Software Development and Validation	432				
83	AF131-167	Thermal Interface Materials for Power System Components	311				
84	AF131-169	Robust Cryogenic Compatible Turbo-machinery and Liquid Rocket Engine coatings	312				
85	AF131-170	Compact High Current Molecular Atomic Particle Beam Generator	312				
86	AF131-175	Micro Airborne Relay Technology	311	612			
87	AF131-176	Reusable Extended Artificial Light Source	842		1		
88	AF131-177	Angle of Incidence (AOI) Measurement Capability	321				
89	AF131-180	Directed Energy Wind Tunnel Test Methodology	843				
90	AF131-181	Computational Modeling of Coupled Acoustic and Combustion Phenomena	843				

		Inherent to Gas Turbine Engines					
91	AF131-182	Non-Fluid Refrigeration Technology for Cooling Infrared Focal Planes and Other System Components below 50 K in Cryo-Vacuum Test Chambers	312	843			
92	AF131-185	Compact Multi-spectral Scene Projector Technology	842				
93	AF131-188	Gas Turbine Engine Particle Emission Characterizatio n	223				
94	AF131-190	Dimensional Restoration of Aircraft Components Damaged by Corrosion	434				
95	AF131-192	Corrosion Identification, Removal and Cleaning of Galvanic Couples in Difficult to Access Areas	433				
96	AF131-196	Landing Gear Strut Operational Readiness Monitoring	433	421			
97	AF131-198	Find substitute for Methylene Chloride in depaint	435	421			

		operations at Hill AFB					
98	AF131-199	Blast Booth Noise Reduction - An OSHA Compliance Issue	435				
99	AF131-202	Surface Treatments for Stainless Steel Actuators	433				
100	AF131-203	High-Efficient Liquid Desiccant and Chloride Removal for Corrosion Mitigation and Control	433				
105	AF141-002	Epitaxial Technologies for SiGeSn High Performance Optoelectronic Devices	842				
113	AF141-016	Persistent Wide Field Space Surveillance	231				
117	AF141-027	Operator Interface for Flexible Control of Automated Sensor Functions	842				
118	AF141-028	Multimodal-Multidimensional image fusion for morphological and functional evaluation of the retina	729				
119	AF141-029	Mobile Motion Capture for Human Skeletal Modeling in	843				

		Natural Environments					
123	AF141-038	Layered Virtualization Detection of Malicious Software Behavior ("Inception")	641	636			
125	AF141-040	Establishing and Maintaining Mission Application Trust in a Shared Cloud	633				
127	AF141-044	Live Patching of Virtual Machines with Limited Guest Support	653				
132	AF141-055	Enhancing Real Time Situational Awareness with Latent Relationship Discovery	232	231			
133	AF141-056	Early Design Analysis for Robust Cyberphysical Systems Engineering	843				
137	AF141-065	Structural Health Monitoring (SHM) Methods for Aircraft Structural Integrity	432				
138	AF141-066	Use more accurate aircraft usage data in predicting life and scheduling inspections	433				

143	AF141-075	Improved Design Package for Fracture Mechanics Analysis	432				
152	AF141-094	Algorithm Based Error Estimation & Navigation Correction	654				
157	AF141-101	Multi-Processor Array for Multi-Parametric Sensing in Cubesat DoD (or Air Force) Space Missions	231	312	1		
159	AF141-106	Innovative Technologies for Operationally Responsive Space	842				
162	AF141-111	GPS receiver cryptography key delivery leveraging NSA's Key Management Infrastructure (KMI)	654				
167	AF141-124	Space-based RF Emitter Detection and Localization Using Field Programmable Gate Arrays	612				
182	AF141-143	Data Analysis and Mining for Penetration Environment Dynamics (DAMPED)	843				
184	AF141-145	Electromagnetic Effects in	321				

		Energetic Materials					
189	AF141-158	Durable, Low Friction Coating for Variable Speed Refueling Drogue (VSRD)	433				
190	AF141-159	Portable Drill-Fastener	433				
194	AF141-165	Standard Test Method for Prepreg Resin Impregnation Level	434				
199	AF141-179	Imaging Techniques for Passive Atmospheric Turbulence Compensation	222				
200	AF141-180	FLIR/3D LADAR Shared Aperture Non-mechanical Beam Steering	222				
201	AF141-181	Enhanced Compute Environment to Improve Autonomous System Mission Capabilities	311			Artificial Intelligence	
206	AF141-186	Advance Tracking Algorithms to Meet Modern Threats	232	231			
208	AF141-190	SATCOM Wideband Digital Channelized Receiver with Low-cost Silicon Technology	612				
210	AF141-193	V-Band Traveling Wave	612				

		Tube Amplifier with Extended Output Power						
217	AF141-203	Improved LHE Zn-Ni and Cd Plating Process	433					
223	AF141-211	Enhanced Fuel Cells From Wastewater Treatment (Bacteria Generated System) as a Renewable Energy Source	461					
225	AF141-214	Beyond Fault Diagnosis and Failure Prognosis Fault Tolerant Control of Aerospace Systems	311	842		Artificial Intellige nce		
226	AF141-222	Hot Surface Ignition Apparatus for Aviation Fuels	843					
229	AF141-228	Arc jet Test-Article Surface Recession Rate Monitor	843					
244	AF151-013	Materials and Designs for Compact High-Voltage Vacuum Insulator Interfaces	322					
249	AF151-019	Optimized Information Display for Tactical Air Control Party	729					
250	AF151-020	F-35 Display Improvement	311					
253	AF151-023	Breathing Air Quality Sensor	311					

		(BAQS) for High Performance Aircraft					
254	AF151-024	Advanced Learning Management System (LMS) for State-of-the-Art for Personalized Training	121				
259	AF151-032	MIMO functionality for Legacy Radios	612				
264	AF151-042	Hierarchical Dynamic Exploitation of FMV (HiDEF)	231			Artificial Intellige nce	
266	AF151-047	Electronic Warfare Battle Manager Situation Awareness (EWBM-SA)	522	245			
267	AF151-048	Cognitive Augmentation for Distributed Command and Control	522			Artificial Intellige nce	
273	AF151-061	Fuel-Property-Independent Injection Technology	311				
275	AF151-063	High-Speed, Two-Dimensional Sensor Suite for Fuel-Air Ratio and Heat-Release Rate for Combustor/Augmentor Stability	311				
285	AF151-078	Ephemeral Security Overlay for GPS	633				

287	AF151-080	Long Term Ultrastable Laser System for Space Based Atomic PNT	654				
291	AF151-084	High-Temperature, Radiation-Hard and High-Efficiency DC-DC Converters for Space	312				
293	AF151-086	A Practical Incoherent Scatter Radar	222				
294	AF151-087	Optimal SSN Tasking to Enhance Real-time Space Situational Awareness	241	552			
297	AF151-094	High Power Density Structural Heat Spreader	312	842			
298	AF151-095	40 Percent Air Mass Zero Efficiency Solar Cells for Space Applications	312				
299	AF151-096	Selecting Appropriate Protective Courses of Action when Information-Starved	522				
305	AF151-104	Rigid-body Off-axis Ordnance Shock/Tail-slap Environment Replicator (ROOSTER)	843				
308	AF151-107	Long-Range Adaptive Active Sensor	222				

310	AF151-109	Hostile Fire Detection and Neutralization	321	322	1		
311	AF151-110	Combined Multiple Classification Methods Using Machine Learning Techniques to Develop VIS-N-IR Spectral Processing	231			Artificial Intellige nce	
312	AF151-111	Campaign-Level Optimized Strike Planner	542				
314	AF151-118	Physics-Based Modeling for Specialty Materials at High Temperatures	842	843	1		
315	AF151-119	Development of Flaws in Complex Geometry Coated Turbine Engine Components for Vibrothermogra phy NDE	842				
318	AF151-122	NDI Tool for Corrosion Detection in Sub-Structure	431				
322	AF151-128	Robust Titanium Surface Preparation for Structural Adhesive Bonding	434				
324	AF151-130	High-frequency Applications for Carbon	842				

		Nanotube-based Wires					
326	AF151-133	Optical Materials Processing for High Linearity Electro-optic Modulators	311	611			
327	AF151-134	Data Management Tools for Metallic Additive Manufacturing	842	843			
329	AF151-136	Modeling Tools for the Machining of Ceramic Matrix Composites (CMCs)	842	843			
331	AF151-141	LWIR Narrow-Band Spectral Filters	222				
334	AF151-144	Electronic Warfare Circumvent and Recover	727				
335	AF151-149	Ka-Band and Q-Band Low Noise Amplifiers	612				
339	AF151-154	Influence of Long-range Ionospheric and Atmospheric Effects on Surveillance and Communication Systems	612				
343	AF151-163	Landing Gear Bushing Installation	434	433			
352	AF153-001	Global Surveillance Augmentation Using Commercial	232				

		Satellite Imaging Systems					
361	AF161-010	Additive Manufacturing Technique for Replacement of Complex Castings	842	843			
365	AF161-016	Radio Frequency Range Modernization, Compatibility and Capability Study	815	843			
366	AF161-017	Prediction of Stress Corrosion Cracking	431				
367	AF161-018	Landing Gear Fatigue Model K Modification	432	431			
369	AF161-022	Installed Systems Near Field Antenna Pattern Measurment System	432	434			
370	AF161-024	Prediction of Boundary Layer Transition on Hypersonic Vehicles in Large-Scale Wind Tunnels and Flight	842				
372	AF161-030	High Speed Extraction of Hyperspectral Images within a Plume Radiation Database Structure	815				
373	AF161-031	Rapid Assessment of	815	843			

		Structural Vulnerability					
375	AF161-034	Fiber Metrology Verification and Validation for High Power Fiber Lasers	322	843			
378	AF161-037	Compact Optical Inertial Reference Unit for High Energy Laser System Line-of-Sight Stabilization	322				
384	AF161-043	PED Operational Domain (POD)	842				Program of record, MDC required
389	AF161-048	Microdosimetry of High Amplitude Ultrashort RF and Electric Fields	841			Industria l Hygene	JCAs fall short on medical industrial hygene (OSHA) complianc e capes
393	AF161-052	Cognitive Airborne Communication s with RF Interference Mitigation and Anti-jam Capabilities (RIMA)	623	727			
397	AF161-057	Secure and Survivable Antennas for Communication in a Nuclear Environment	726				
406	AF161-067	High-Performance Body Armor-Integrated, Multifunctional	313				

		Batteries for Dismounted Soldier					
407	AF161-068	High-Temperature Electric Wires	311	842			
413	AF161-074	Durable Pre-cooling Heat Exchangers for High Mach Flight	311				
422	AF161-084	Cognitive UHF Radio for Enhanced GPS Crosslinks	654				
425	AF161-087	Algorithm Development for WFOV Mission Data Processing	231				
427	AF161-089	Development of Flat Lens Technology	842				
428	AF161-090	High Data Rate/Low SWaP-C GPS Crosslinks	654				
435	AF161-097	Novel High Transmittance Curved Surface Laser Eye and Sensor Protection	728				
437	AF161-099	Ultra Miniature Beam Steered Laser Radar System	311				
438	AF161-100	Multi-Axis Precision Seeker-Laser Pointing Gimbal	311				
439	AF161-101	Fiber Optic Networking Technology for Advanced Payload	311				

		Integration on F-35 and Other Platforms					
443	AF161-106	Compact SWIR DFOV Optics	311				
445	AF161-108	Innovative, Cost-Effective Techniques for Antenna Electronic Beam Steering	321				
448	AF161-111	Manufacturability Improvements for Highly Integrated Monolithic Exploding Foil Initiator	321				
451	AF161-114	Alternative Nondestructive Testing Inspection Method of In-service Aircraft Bolts and Wheels	432	431			
453	AF161-116	Rapid, Local Characterization of the Fatigue Crack Growth Behavior	842				
461	AF161-124	Accelerated Adhesive Cure for Nutplate Repair	434				
464	AF161-127	Chromium-Free Flexible Primer	433				
467	AF161-130	Innovative Application and Modifications of Scanning Kelvin Probe Technologies for Measurement	431				

		of Coating Degradation and Detection of Corrosion					
468	AF161-131	Airborne Graph Analytics Applications for Multi-sensor Fusion and Integration	243	241			
476	AF161-139	Automated Target Recognition (ATR) Detection from Laser Imaging Detection and Ranging (LIDAR) Data	231				
478	AF161-141	Integrated Circuit Authentication and Reliability Tool and Techniques	422				
480	AF161-144	Continuous High Pulse Repetition Frequency (HPRF) Mode for Anti-Access/Area Denial (A2AD)	311				
481	AF161-145	Compact Wideband Direction Finder	842	843			
483	AF161-147	High Performance Global Positioning System (GPS) M-Code Acquisition Engine	654				
485	AF161-149	Synergistic/Combine Radio	231				

		Frequency/Electro-Optical (RF/EO) Processing for Synthetic Aperture Imaging (SAR)						
487	AF161-151	Automated 3D Reconstruction of a Scene From Persistent Aerial Reconnaissance Video at High Zoom	232					
488	AF161-152	Broadband Beam Steering Devices for Midwave Infrared (MWIR)	722					
494	AF162-007	High-Efficiency Radiation-Hard Solar Array Interface to Spacecraft Power System	312					
496	AF162-009	Electric Propulsion for Dual Launch	312					
498	AF162-D001	Mitigation of Small Unmanned Aircraft Systems (sUAS) Threats	713					
510	N06-032	Thermal Barrier Coating Environmental Durability Enhancement (CMAS)	433					JCAs lack coverage of sustainment functions.
512	N09-T021	Development of Low-Cost Tracking System for Infantry Training	121					

513	N111-062	Geographic Information System Tools for Spatio-Temporal Statistics	654				
514	N121-078	Enhanced Summarizations of Streaming Text	245	241			
528	OSD09-EP2	Power Generation and Storage for Micro Aerial Vehicles (MAV)	311				
531	OSD10-CR1	Rapid Assessment of Team Cognitive Readiness	114			Human Performance	JCAs lack coverage of human performance
541	OSD13-HS2	Virtual Verification Test Bed for Robust Autonomous Software Operation in Complex, Unknown Environments	843				
544	OSD13-PR5	Improved Turbo/Superchargers for UAS/UGS Application	311	312			

Appendix J. JCA Assignment Logic for SBIR Topics

Table 23. JCA Assignment Logic for SBIR Topics

JCA	Tier 1 Desc	Tier 2 Desc	Tier 3 Desc	Assignment Logic

114	Force Integration	Force Management	Readiness Reporting	End capability is to determine mission/unit readiness
121	Force Integration	Force Preparation	Training	End capability is to train forces
222	Battlespace Awareness	Collection	Imagery Collection	End Capability is to solely collect imagery data
223	Battlespace Awareness	Collection	Measurements & Signatures Collection	End capability is to solely collect measurement and signature data.
231	Battlespace Awareness	Processing / Exploitation	Processing	End capability is to process collected data (Make raw data readable)
232	Battlespace Awareness	Processing / Exploitation	Exploitation	End capability is to transform processed data into intelligible information for immediate use.
24	Battlespace Awareness	Analysis, Estimation, & Production		End capability consists of analysis, estimation, and production. (Large scope topic)
243	Battlespace Awareness	Analysis, Estimation, & Production	Interpretation	End capability is to identify, assimilate, and correlate various intelligence data.
245	Battlespace Awareness	Analysis, Estimation, & Production	Product Generation	End capability is to document intelligence data that provides actionable intel that increases situational awareness (Can be in any medium).
311	Force Application	Maneuver	Air	End capability is to operate an aircraft (includes avionics, payload operation, and power plant systems.
312	Force Application	Maneuver	Space	End capability is to operate a spacecraft (includes avionics, payload operation, and power plant systems.
313	Force Application	Maneuver	Land	End capability is to operate a land vehicle or as ground personnel.
321	Force Application	Fires	Kinetic	End capability is to provide a kinetic type munition (includes bomb or missile).
322	Force Application	Fires	Electromagnetic	End capability is to provide an EM type munition

				(includes lasers/directed energy).
42	Logistics	Supply	Supply	End capability consists of supplies/equip and inventory management (broad topic).
421	Logistics	Supply	Supplies & Equipment Management	End capability is to maintain accountability over inventory.
422	Logistics	Supply	Inventory Management	End capability is to receive and evaluate quality of inventory. (Includes Just in time inventory systems)
43	Logistics	Maintenance (Depot & Field)		End capability includes all maintenance functions (broad topic).
431	Logistics	Maintenance (Depot & Field)	Inspect	End capability is to conduct inspections of components/systems (includes non-destructive inspection)
432	Logistics	Maintenance (Depot & Field)	Test	End capability is to evaluate condition of components/systems to a standard (includes analysis and simulations of conditions, fatigue, and corrosion)
433	Logistics	Maintenance (Depot & Field)	Service	End capability is to conduct regularly scheduled service of aircraft (includes depot level maintenance)
434	Logistics	Maintenance (Depot & Field)	Repair	End capability is to conduct repairs of components/systems at below the depot level (includes flight line maintenance)
435	Logistics	Maintenance (Depot & Field)	Rebuild	End capability is to restore a specific component or part into serviceable condition (includes total component reconditioning)
461	Logistics	Engineering	General Engineering	End capability is to provide infrastructure and modify,

				maintain, or protect the physical environment.
462	Logistics	Engineering	Combat Engineering	End capability is to provide contingency/combat supporting infrastructure and engineering services.
472	Logistics	Base & Installation Support	Installation Services	End capability is to deliver selected services not related to real property or personnel services to meet the requirements of the installation population and mission (includes water and power supply).
52	Command and Control	Understand		End capability covers all of organizing, developing, and understanding information about the operational environment. (Broad Topic)
522	Command and Control	Understand	Develop Knowledge & Situational Awareness	End capability is to develop knowledge and SA from information.
532	Command and Control	Plan	Apply Situational Understanding	End capability is to provide SA to determine courses of action.
542	Command and Control	Decide	Select Actions	End capability is to provide decision making capabilities or enhancement to deciding from courses of action.
612	Communications & Computers	Information Transport	Wireless Transmission	End capability is to provide wireless transmission of data (includes communications data)
620	Communications & Computers	Network Management	Network Management	End capability is to provide wired transmission of data (includes communications and diagnostic data)
623	Communications & Computers	Network Management	Spectrum Management	End capability is to minimize interference between electronic devices across the electromagnetic spectrum
631	Communications & Computers	Cybersecurity	Information Exchange Security	End capability is to protect the exchange of information from interception or corruption.

633	Communications & Computers	Cybersecurity	Data Protection	End capability is to protect the integrity of stored data.
641	Communications & Computers	Defensive Cyberspace Operations (Internal Defensive Measures)	Cyberspace Defense	End capability is to deter and counter cyberspace attacks.
653	Communications & Computers	Enterprise Services	Common Enterprise Services	End capability is to provide a common computing capability across a network at the AF or DOD level.
654	Communications & Computers	Enterprise Services	Positioning, Navigation, & Timing	End capability is to provide navigation services (includes GPS and inertial navigation)
711	Protection	Prevention	Concealment/Stealth	End capability is to provide stealth or concealment.
713	Protection	Prevention	Counter Air & Missile	End capability is to protect ground based forces/equipment/infrastructure from air based and missile attacks.
722	Protection	Mitigation	Projectile	End capability is to protect forces (ground and air) from projectile attacks (includes bullets and missiles)
726	Protection	Mitigation	Nuclear	End capability is to protect forces (ground and air) from nuclear attacks.
727	Protection	Mitigation	Electromagnetic Effects	End capability is to protect forces (ground and air) from electromagnetic effects (includes jamming effects)
728	Protection	Mitigation	Directed Energy	End capability is to protect forces (ground and air) from directed energy attacks (includes lasers).
729	Protection	Mitigation	Natural Hazards	End capability is to protect forces (ground and air) from natural hazards (includes natural to job/work hazards and environmental exposure)

815	Corporate Management & Support	Advisory & Compliance	Operational Test & Evaluation	End capability is to conduct operational test of something.
842	Corporate Management & Support	Acquisition & Technology	Advanced Technology	End capability is too far advanced to place within current capabilities or is defined out of the scope of a capability (includes artificial intelligence)
843	Corporate Management & Support	Acquisition & Technology	Developmental Engineering	End capability is to support the development or design function for a program of record and conduct developmental testing.

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14. ABSTRACT

The United States Small Business Innovation Research (SBIR) Program invests $2.2 billion annually into domestic innovation stimulation. The Department of Defense (DoD) contributes almost $1 billion of that investment; of which the Air Force accounts for 25%. Commercialization, either the transfer to programs of record or further industrial investment, is the program's objective. Data from this research indicates that Air Force programs have a 7.6% commercialization rate; representing an opportunity to improve. Leveraging best practices from industry; this research provides a method to align investments with needed capabilities. This method exploits established user need taxonomies, the DoD Joint Capability Area (JCA) listing and the National Aeronautics and Space Administration's SBIR taxonomy, to categorize SBIR efforts. This categorization allows for needs based innovation portfolio management. Metrics are developed that identify several technologies of interest that over perform and underperform relative to the overall portfolio. This development of metrics and visualization tools provides managers a new means to control and improve their innovation investments. This needs based mapping facilitates sharing and coordination amongst aerospace SBIR stakeholders. This thesis concludes by recommending improvements to the existing JCAs, the SBIR topic development process and the establishment of an aerospace SBIR community of interest.

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